The background of the book cover is a deep black space filled with various celestial objects. Several bright, out-of-focus galaxies are visible, some appearing as soft, glowing clouds of light. A prominent feature is a bright, multi-colored nebula in the center-left, showing vibrant green, red, and blue hues. Other smaller, bluish-white star-like objects are scattered across the field of view, creating a sense of vastness and cosmic wonder.

Werner Brückner
Black Holes
And Beyond

From Hypothesis to Detection

Werner Brückner

Black Holes And Beyond

from Hypothethis to Detection

Front cover: Press Release 1332 of the “European Southern Observatory“ ESO from July 2013 © S.Gillessen (MPE). Headline: Fo “New observations from ESO’s Very Large Telescope show for the first time a gas cloud being ripped apart by the super-massive black hole at the centre of the galaxy. The cloud is now so stretched that its front part has passed the closest point and is travelling away from the black hole at more than 10 million km/h, whilst the tail is still falling towards it”.

The photograph taken at widely separated time intervals, shows how the gas cloud has arrived at the black hole in the centre of the Milky Way. It is the first proof that black holes really do exist, but by its very nature, the black hole itself cannot be seen.

Werner Brückner, Dipl.Ing. (FH) of Physics, was born 1950 in Göppingen, South Germany. He studied at the Naturwissenschaftlich Technische Akademie under Prof. Dr. Grübler in Isny, Germany, and is currently working at the Institut für Rundfunktechnik (Radio Technology) in Munich. He is also a member of the public observatory there.

Annotation:

This book includes formulae for which some knowledge from a college course, would help but is not essential to enjoy the book. It is for future students of science subjects and also for those simply interested in Astronomy and Astrophysics. It will help a reader to know that this book is specifically an *introduction* to this fascinating subject, with the intention of providing a very wide overview assisted by many illustrations, putting it ahead of similar books but without going too deeply into the details which The Specialist might expect. This keeps the book more readable to the popular science enthusiast who may go on to seek more advanced material.

I have to thank my friend **Howard Murray**, Stockport, England for his translation from my English writings. He enjoyed the work but of course kept the book British concerning the selection of some phrases. American readers surely will forgive this.

Content

Foreword.....7

Introduction.....8

Early History.....10

The Creation of the Universe.....39

The Birth Of Stars.....41

The End Of Stars.....56

Flight to A Black Hole.....77

Inside A Black Hole.....95

The Smallest and the Biggest.....110

The Contribution of Quantum Physics....115

The Contribution of String Theory119

The Power of Mathematics.....122

Current Results of Research.....129

Different Views.....135

Epilogue.....136

Foreword

Black holes are amongst the most fascinating subjects in Astrophysics. They are at the centre of research and are of great importance in cosmology. The reader will be informed of the latest state of knowledge at 2013, including the newest discovery of a black hole in the centre of the Milky Way. The book also deals with the history of black holes, beginning with Medieval times when nobody knew of what a star consisted. The breathtaking development in Physics and Astronomy has been so fast that there is now a need for overview and summary.

This book is aimed at the reader who is interested in popular science. It is based on facts garnered by highly respected organizations like the ESO, NASA and one of the greatest world wide research institutes, the Max Planck Institute of Science. This book also tries to present complex information in an enjoyable form, achieved with the help of illustrations and graphics which get directly to the point.

The book employs a step by step approach to assist the reader in the under-standing of the complexity of theory regarding black holes. The physics of star formation alone, could justify a separate book. Just as the understanding of the early cosmos is changing steadily, so also is the understanding of black holes.

Related to the issues of black holes, there is further information at the end of the book in the form of a list of internet addresses which might be of interest to the reader.

Introduction

A Black Hole is a celestial body whose gravitation is so immense that nothing can escape its influence, not even light. As we know now, there are plenty of them. The discovery is surely one of the greatest advances in the last ten years. They were predicted by theory which is a crowning achievement for Mankind. Surprisingly, the history of the discovery goes way back in history. But because they are black they are hard to see and to detect. Since the discovery of a supermassive Black Hole in the centre of the Milky Way, such objects have been discovered in nearly all galaxies. Only now are we beginning to understand just how closely the formation and the destiny of galaxies are influenced by black holes.



Our Milky Way with the bright centre concealing a Black Hole

(By courtesy of the European Southern Observatory, ESO)

It is possible that human beings could not exist without them. They attract, in a double sense of the word. On one hand they attract matter because of their immense gravity and on the other hand they are attractive to Scientists and non-Scientists alike because of the many secrets which accompany their existence.

They certainly do exist out there in space. They have now entered every day language. Something which disappears and can't be found is said to have "disappeared into a black hole". It is a saying which can be heard in daily speech and has become a euphemism for something which gets lost for ever.

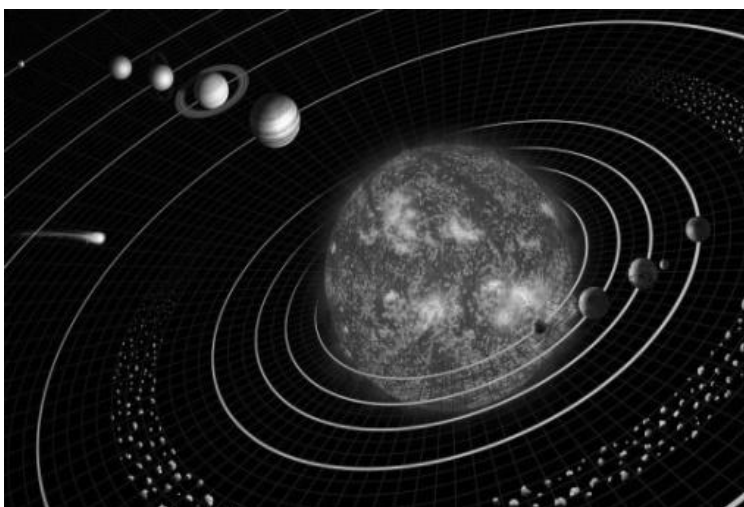
So, to where does all the poor unfortunate prey of a Black Hole go? Victims come in all sizes, sometimes consisting of complete sun systems including their planets and sometimes even whole galaxies are eaten up by the monster, step by step. Black holes are frightening!

Pre-occupation with the subject soon leads us to the fundamental questions of Mankind: Where do we come from? Where are we going?

The Astrophysicist gives some surprising answers. This is now becoming possible because of large-scale projects like the Large Hadron Accelerator in Geneva and by big telescopes like the "Very Large Telescope" of the ESO in Chile.

Early History

In the 17th Century, little or nothing was known of the nature of stars or their relationships. Neither was it clear if our Sun was constructed of the same matter as the thousands of other sparkling stars in the night sky. People thought that The Sun contained vast quantities of burning coal. However, when seen through telescopes invented at the end of the 16th century, different colours could be observed. Some stars appeared more red, some more blue, but most were radiating white light. As the consequence of that, it became apparent that all stars were *not* the same. However, the difference in brightness of the stars *was* correctly explained by their unequal distances from Earth. Nobody knew anything about **Black Holes** – the name was yet to be coined. However, the laws of celestial mechanics were already known, owing to the work of one Johannes Kepler, a German astronomer. It was Kepler who had calculated the times of planetary orbits, according to their distances from The Sun. Today this is known as Kepler's Laws of Planetary Motion. At this time however, the force which held the planets in their orbits of The Sun was still unknown. Obviously there was a secret, long ranging force present.



*The emergence of
our planetary
system
(Artist's
impression, Wiki)*

Suddenly in the 17th Century, appeared the genius **Isaac Newton**, President of the Royal Society in London and Lucasian Professor of Mathematics at the University of Cambridge (as later was the famous Stephen Hawking from 1979 to 2009).



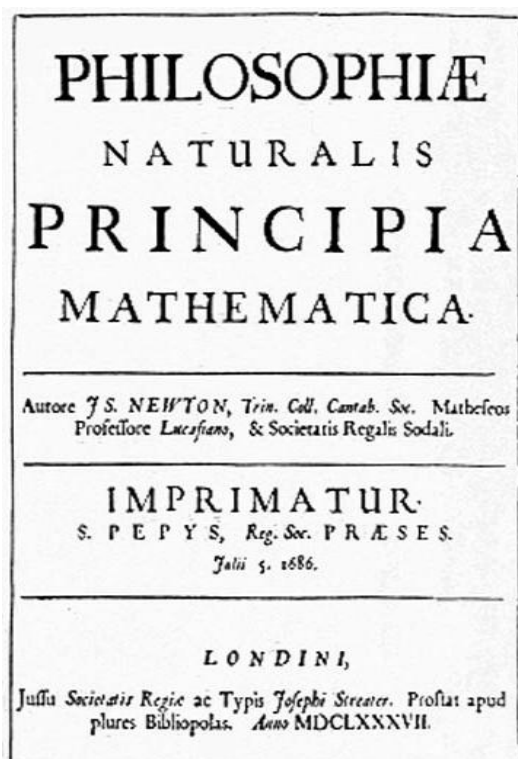
*Sir Isaac Newton, 1632
- 1726, discovers the
fundamental laws of
mass attraction through
gravitation (Wiki)*

Together with Gottfried Leibnitz, Newton is credited as the inventor of Infinitesimal Calculus and he was the first to contemplate the nature of light and the essence of gravity.

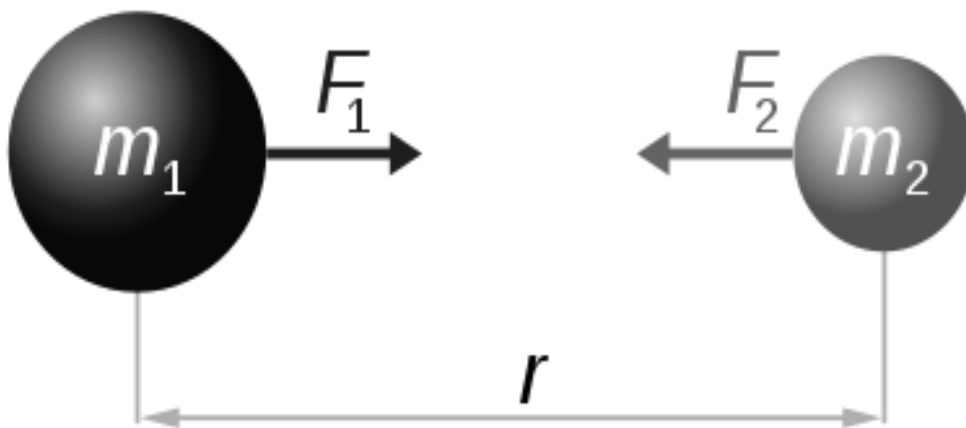
The controversial tradition is that it was a falling apple which caused him to think about gravity, whilst sitting under an apple tree. He also invented more practical applications. A telescope using a mirror as a reflector at the back instead of a lens in the front carries his name, The Newtonian Telescope, to this day.

Newton was first to devise a correct interpretation of gravity and to define the Laws of Motion in formulae. He was the one to conclude that it is the Earth which makes the apple fall, by gravitational pull. Conversely, there must also be an influence albeit small, by the apple upon the Earth. Newton had formulated his Laws of Motion already by 1686, describing the relationship between a body or mass and the forces acting upon it. Including Kepler's laws of planetary motion he was able to formulate a law of Universal gravitation, which is also valid for black holes. Of course these bodies were as yet unknown in Newton's time, therefore he made no mention of them.

Newton definitely discovered the relationship between mass and the force of attraction but he did not unravel the understanding of gravitation, its nature or essence. However, knowing the Nature of gravitation is the key to understanding black holes which impose enormous gravitational forces, as we will see in the next pages.



*Newton's great
legacy, in Latin. A
giant step forward in
the understanding of
the laws of nature, as
early as 1686 (Wiki)*



$$F_1 = F_2 = G \frac{m_1 \times m_2}{r^2}$$

Newton's formula for calculating the attraction between two masses, first published in the year 1686 (Wiki)

Newton's Law of Universal Gravitation is valid for all 'point masses' on Earth, in fact the entire Universe. It deals with two point masses named m_1 and m_2 in the distance r . The force between them is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. G is a constant. If we consider a black hole to be a point mass, the formula is valid for those as well.

Basically, this formula already reveals the problems which arise when the distance r is set at Zero, meaning that the celestial bodies have zero distance. By the law of mathematics, the result will become infinite. In mathematical calculations this is no problem. Mathematicians use this symbol for something which becomes infinitely large: ∞

How would we interpret it in physical terms? Can the force of attraction F become infinite, when two masses are aggregated to one point?

This would be a force stronger than anything known in The Universe. As a consequence of that, Newton's formula can't be valid for very *small* distances.



*“Infinity? I
cannot conceive.
it“ (Photo:
R.Brückner)*

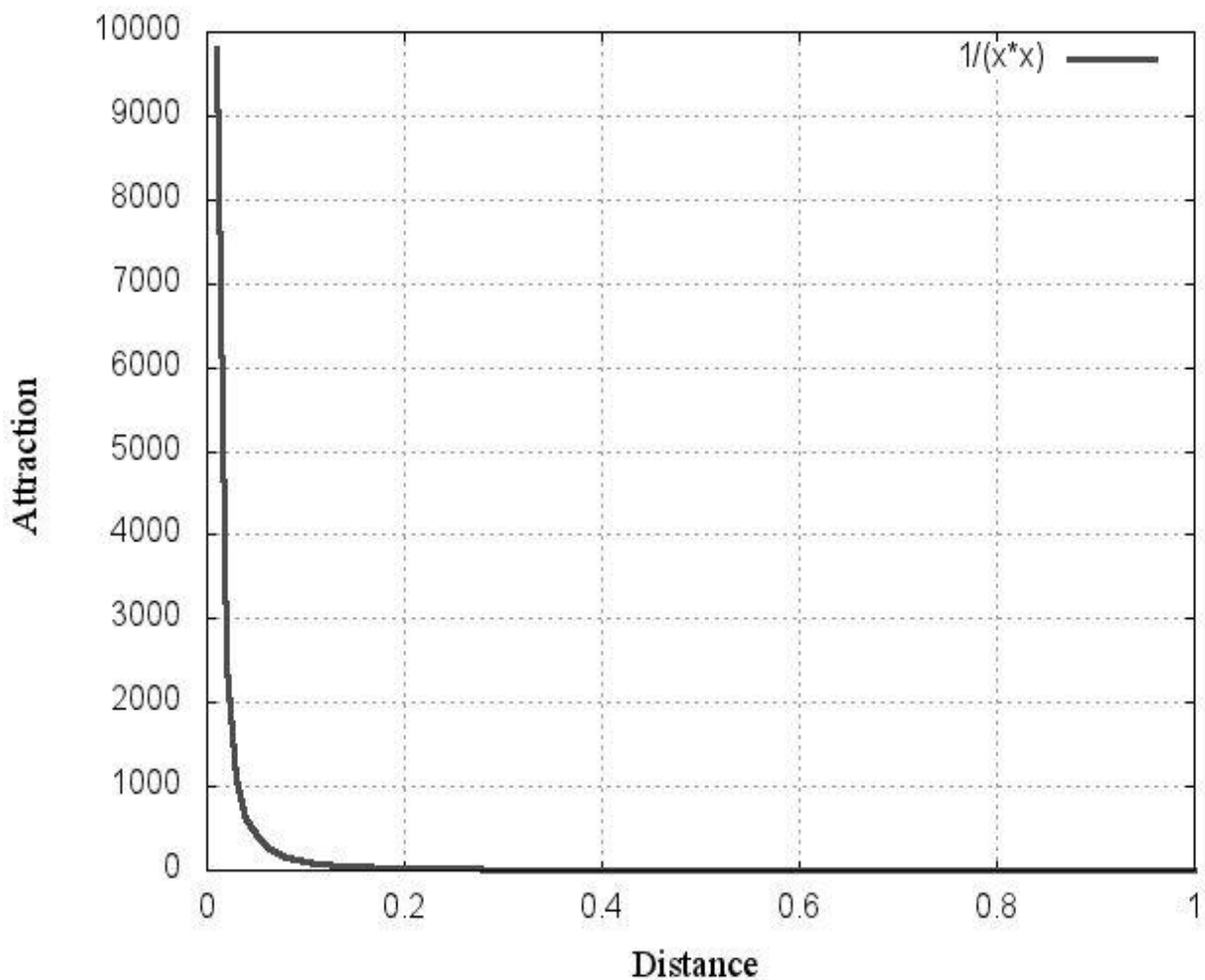
The human brain seems to be incapable of comprehending the concept of ‘beyond infinity’ but *can* cope with finding solutions for real, earth-bound problems. For us, forces and distances on earth are easier to handle. Astronomical distances and forces overwhelm our thinking because we do not need them for Earthly survival.

Only 70 years after the death of Newton, **Henry Cavendish** calculated the constant G as a very low number. Cavendish was a British philosopher and scientist and is noted for his discovery of hydrogen which he called “inflammable air”. Much later it transpired that just the element hydrogen is essential for the building of stars and equally for black holes. So is the constant G .

$$G = 6,673\ 82 \times 10^{-11} \frac{\text{m}^3}{\text{kg} \times \text{s}^2}$$

This physical constant G is a natural constant determining how much two masses will attract each other. It is a distinct number. Were this number smaller, two masses would attract themselves to a lesser degree. e.g. The Sun & the Earth. As a consequence, the Earth would orbit at a greater distance from the Sun. Hence this could result in the Earth's receiving much less light and heat than is actually the case. It could possibly become too cold to sustain life.

Conversely, if the number G were greater, the Earth would orbit much more closely to the sun. The resulting greater temperature would render life quite impossible, water would evaporate and we might have the same conditions as exist today on the planet Venus. For that reason, it is crucial to all life that the physical constant G is as it is. This is not self-evident because G is related to space and time, and both are able to change as we will see in the next chapters. On the next page Newton's formula is depicted in a diagram. The power of attraction F versus the distance r of the two masses m_1 and m_2 will be seen.



Newton's formula displaying the Force of Attraction F versus the Distance of 2 Masses (plotted with GnuPlot)

In that diagram, it will be seen that when the distance r between two masses is reduced, the forces between them increases. In the case that the two masses concentrate at one point, the force F will become infinite. The computer program running "Gnuplot" locked up when $F=10^4$ was exceeded.

If we assume one of the two masses to be a star and the other to be a black hole, there would be no way for the star to escape the black hole. The star would simply be dispatched and gulped by the Black Monster. Apparently a black hole is a lone wolf capable of massacring everything in its path.

NEWTON'S THREE LAWS OF MOTION

First law of motion: an object continues in its state of rest unless compelled to change that state by an external force

Second law of motion: if a force acts on an object, it will cause an acceleration

Third law of motion: for every action there is an equal and opposite reaction

Is. Newton



*Trinity College in
Cambridge, build 1350,
later the domain of Isaac
Newton (Wiki)*

We can summarise the positions in Physics until the end of the 19th. century as follows :

- Space and Time exist in objective evidence and are especially independent of the motion of any corpus or body.
- There is no interdependence between Space and Time, neither is there inter-relationship between them.
- Space is infinite in its dimension. All points and all directions in space are equivalent.
- Time has one dimension and is infinite. Therewith are past, present and future determined precisely.
- Space and Time are ubiquitous. This means that physical dimensions of a body and the duration of an event are independent of any celestial reference system.

All the above mentioned assumptions were – as we now know – either *wrong* or severely limited!



The world view at the beginning of the 20th century, was changing rapidly, old theories very often being consigned to the waste paper basket .

In the late 18th century, the English parson and teacher **John Michell** predicted the existence of massive stars with gravity so strong that their escape velocity would exceed the speed of light. Michell was Rector near the city of Leeds in the UK. The idea struck him in 1783 while considering a hypothetical method to determine the mass of a star. In those days nobody knew anything of a star's composition. It was thought that the Sun was an enormous heap of burning coal. Michell accepted Newton's theory that light consists of small particles having mass. He used Newton's formula and calculated that suns having a mass 500 times the mass of our Sun would induce such a strong attraction that even light couldn't leave the surface. He declared that it therefore follows that these suns can't be seen from Earth. Moreover, Michell, presumed that such dark stars might reveal their existence by the movement of other stars which are close to them. This all came true as we know today. He correctly predicted black stars. These stars have been called Black Holes since 1967.

"If the semi-diameter of a sphere of the same density as the Sun were to exceed that of the Sun in the proportion of 500 to 1, a body falling from an infinite height towards it would have acquired at its surface greater velocity than that of light, and consequently supposing light to be attracted by the same force in proportion to its vis inertiae (inertial mass), with other bodies, all light emitted from such a body would be made to return towards it by its own proper gravity."

Ref. J.Michell, an Abstract from the "Philosophical Transactions of the Royal Society of London", 1783

Later in the year 1801 the German astronomer Johann **Georg von Soldner** calculated the deflection of starlight by Newton's gravitational. Soldner became Director of the Munich Observatory in 1815 and his calculations on the deflection of the light by heavy stars were later used by a physicist named Albert Einstein. Soldner speculated on the possibility of a massive dark object in the middle of The Milky Way. People still were unsure of the character of light. Light particles or photons – as we call them today - were supposed to have mass of course, but there were doubts. Today we know for certainty that there is a black hole with immense gravity in the middle of our Galaxy. That is what this book proposes to address.



*Portrait of Johann
Georg von Soldner,
1776 – 1833, German
Physicist, Astronomer
and Geographer (Wiki)*

Knowing the precise velocity, one could calculate distances in space with even higher accuracy. e.g. the distances to celestial objects like planets and stars. It was simply not possible to measure the speed of light with the available, medieval instruments because of the very high value of the speed of light. Light was always supposed to be infinitely fast. Additionally, the nature of light and its composition, was not understood. Light was supposed to be particles like small balls bouncing off on mirrors. **Christiaan Huygens** explained in the 17th. Century that light consists of waves and not particles. He arrived at that conclusion by observing the behavior of light in water and in a glass prism, turning a white beam coloured. If light is waves, like water waves, what was the carrier? The Ether was proclaimed. A dilemma then arose: who was right, the one declaring light to be waves or the other one saying light is particles consisting of nothing more than photons? The next generation of physicists spoke of the dual character of light (which means, both are right). depending upon the situation in which the observation was made.



Christiaan Huygens, 1629-1695, was a prominent Dutch mathematician and scientist.

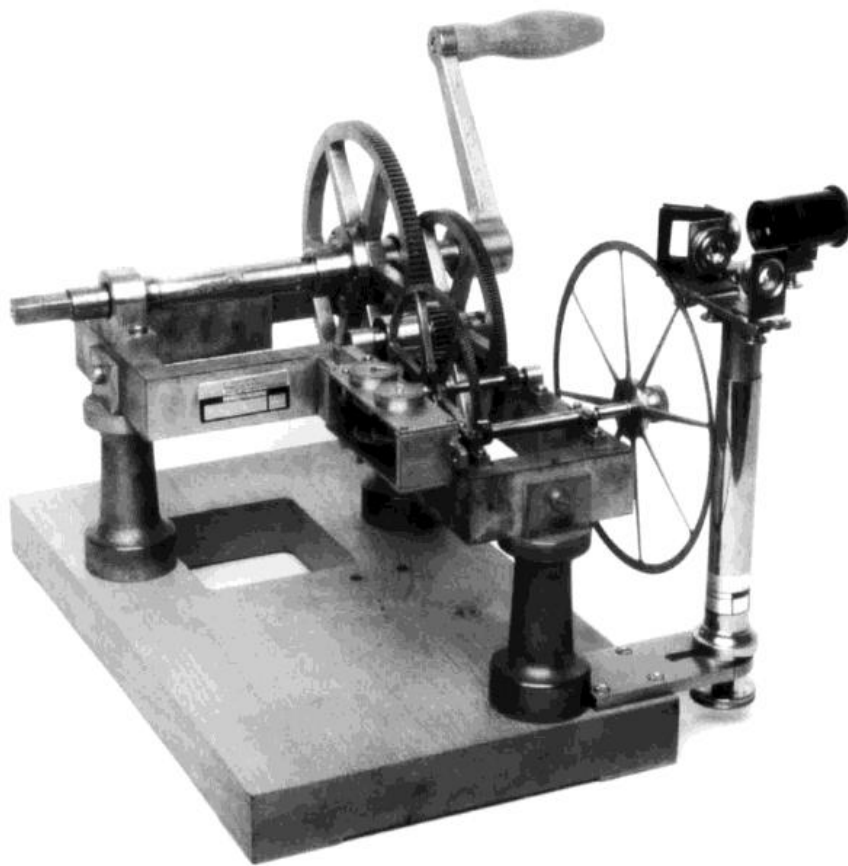
The first calculation of the velocity of light was achieved by a scientist from Denmark in 1676. **Ole Römer** noticed a delay in the time of arrival when observing one of the Jovian moons, by name Io. Depending on its position (relative to Earth), light arrived a little later than was calculated by Kepler's laws. Römer interpreted the missing 10 minutes as the duration that light needed to reach the Earth because Jupiter was in conjunction with Earth. Obviously the light needed slightly longer to travel the distance which was being used by him to calculate the speed of light.



Ole Römer, 1644- 1710, born in Copenhagen, Denmark. The first Astronomer scientifically to calculate the velocity of light (Wiki)

Ole Römer's measurements of Jupiter's moons very closely approached the values we have today. Considering the known distances between Earth, Sun and Jupiter, he calculated a value for the velocity of light at 212.000 Km/s. This is close to the correct value of 300.000 Km/s which equals 186,000 miles per second.

After Ole Römer, **Armand Fizeau** succeeded in 1848 in calculating the very first accurate value of the speed of light. He sent a light beam through the holes of a rotating wheel to a mirror at some miles distance. This mirror reflected the beam again through the holes. By measuring the rotation speed of the wheel when the beam was visible again, it was possible for him to determine the velocity of light to within 5% of the value we have today.



*Reproduction of Fizeau's rotating wheel,
designed for measuring the speed of light
(Wiki)*

The exact value of the speed of light in a vacuum is $c = 299,792,458$ metres in each second, equivalent to 186,282 miles per second – the highest known speed in space. Nothing is faster.

The Michelson-Morley-Experiment was conducted by the German-American Physicist Michelson in Potsdam, near Berlin in 1881 and later by the American chemist Morley in Cleveland, Ohio.

For that purpose, a system of mirrors was mounted on an optical table in such a manner that one axis or pivot pointed in the direction of the trajectory of Earth around the Sun and another pivot at right angles to that trajectory. With an ingenious mirror system, the light beams were reflected and created interference fringes. With the help of that table, one could measure the *difference* in the velocity of light in both paths but not the velocity itself. It was anticipated that the velocity of light would increase in the direction of the trajectory path, Earth around the Sun by 30 km/s because that is the speed at which the Earth circles the Sun. This was not the case. Apparently the velocity of light is always the same, independent of the direction in which the measurement is carried out. Furthermore, following that experiment, the existence of a medium called “Ether“ could be discounted. Unlike waves in water, light needs no medium.

Michelson's optical experiment, built 1881, confirming the constant speed of light. A replica can be admired at the Michelson-house in Potsdam, Berlin (Wiki)



Eventually, it became clear that the velocity of light is a further fundamental and natural constant, like Newton's gravitational constant G . If light takes time to travel from the stars to Earth, then looking into space is always looking back in time. The more distant the stars are from Earth, the longer light needs to reach The Earth. For instance, light has about 8 minutes transit time from the Sun to Earth. That means that we only ever see our Sun as it was 8 minutes ago.

In one year, light will travel the unimaginable distance of 9,460,800,000,000 km or 10^{13} km. This is also known as 1 light year and is a measure of *distance*. The distance to our next nearest Solar system, called Alfa Centauri is about 4 light years. The distance to our nearest Galaxy, named "Andromeda" is about 2.5 million light years. That means, we don't see Andromeda as it looks now but how it looked 2.5 million years ago. The Universe is entirely history.

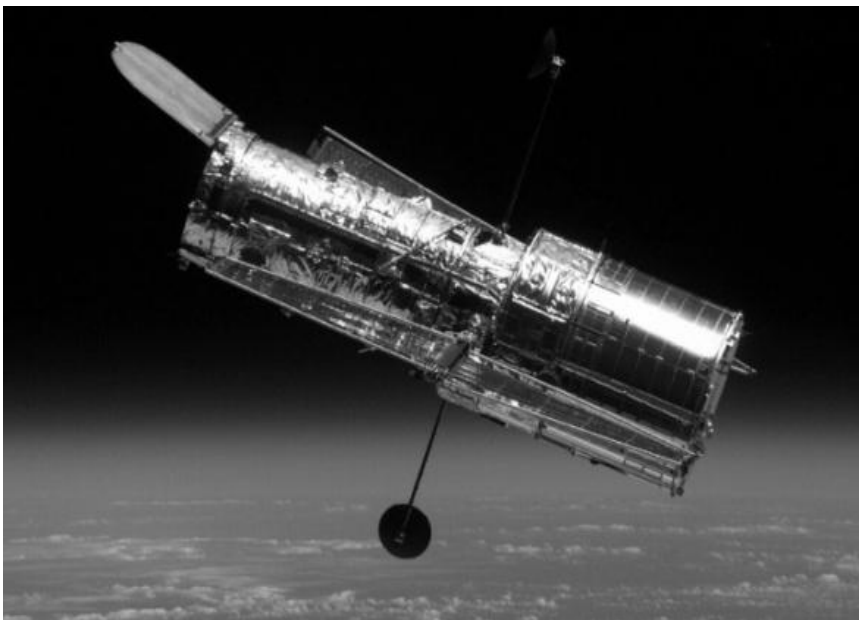


Photo of the Andromeda-Galaxy, taken by amateurs of VSW Munich, visible by naked eye in a clear night sky

A Light-year is a measure of distance.
Others are:

- The Parsec (pc) and the
- Astronomical Units (AU)

With the Hubble space telescope, the most distant, visible Galaxies are at a distance of 10 billion light years. This means, the deeper we can look into space, the more we see back in time – perhaps to its beginnings. There are similarities with ground test drillings on Earth. We look further back in time the deeper we drill. Similarly, a look with the help of a telescope to far distant Galaxies is always a view into the past – and that is simply because light has a finite velocity.



The Hubble Space Telescope (HST) .Placed in orbit in 1990, still in service today. Images show furthest Galaxies at a distance of 10 billion light years (By courtesy of NASA)

Let us return to Black Holes. **Karl Schwarzschild**, former Director of the Potsdam Observatory, near Berlin, contemplated Black Holes in about 1900. He assumed that there is a relationship between the size of a black hole and its mass. He called the centre of a black hole, a *Singularity*. In addition, he postulated an outer border, a radius where black holes finish. We call that radius the *Schwarzschild Radius*. This radius encompasses a huge area called the *Event Horizon*, the border which is the point of no return for approaching matter. It can no longer escape because of the immense gravitational pull of the hole.

Vice versa, neither can light *inside* the black hole escape, being permanently imprisoned. With these definitions Schwarzschild compounded his basic ideas for the black holes with which we are dealing so far. They became key words in Astro Physics.



Karl Schwarzschild (1873-1916), former Director of the Observatory in Potsdam, Berlin (Wiki)



*The former observatory Potsdam Berlin, place of
Karl Schwarzschild (Wiki)*

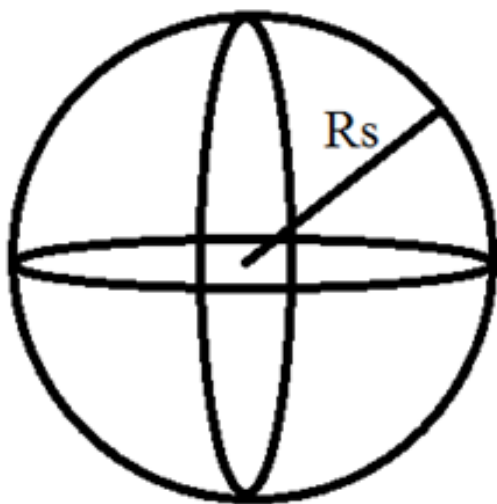
Schwarzschild was the first to calculate the size of a black hole which is determined by its radius R_s and its inherent mass M only. He found a simple relation between both:

$$R_s = 2GM/c^2$$

The formula shows that there will be black holes in different sizes: big and small ones depending on their masses. If further mass is gathered by the black hole, it will become greater and its radius will grow in proportion to the collected masses when for instance, stars are captured. The formula also contains Newton's gravitational constant G of which we are already aware and c , the velocity of Light, also a constant.

He also suspected that black holes arose from big stars. The bigger a star is, the greater will be its Schwarzschild Radius later, when a star transforms into a black hole. Schwarzschild explained the different sizes of stars by the difference in clouds in Space, at the birth of the Universe. He assumed the distribution of the gas clouds to be the result of chance.

The Event Horizon, so he stated, is not a fixed nor solid surface but more a border. Beyond that horizon, observation is impossible – invisible for all external watchers. All observation is limited and ceases at that surface.



The Schwarzschild Radius R_s is the radius which connects the centre of a black hole with its event horizon

Schwarzschild limited his calculations and assumed the most simple form of a black hole, to have no spin and no electrical charge. In reality, we deal with fast rotating black holes having spin and perhaps electrical charges forming large magnetic fields which can be detected from a distance.

In the early twentieth Century, the Indian Physicist Subrahmanyan **Chandrasekhar** wondered if there were a limitation to the mass of the stars known as Red Giants. The name came from its red radiation. These stars are expected eventually to collapse to a black hole.

He was a student at Oxford, UK. In the holidays, on the way back to his home country India, and in 1930 aboard ship, he found himself with time to muse on black holes. (the journey lasted three months). He wondered just how small, black holes might be formed.

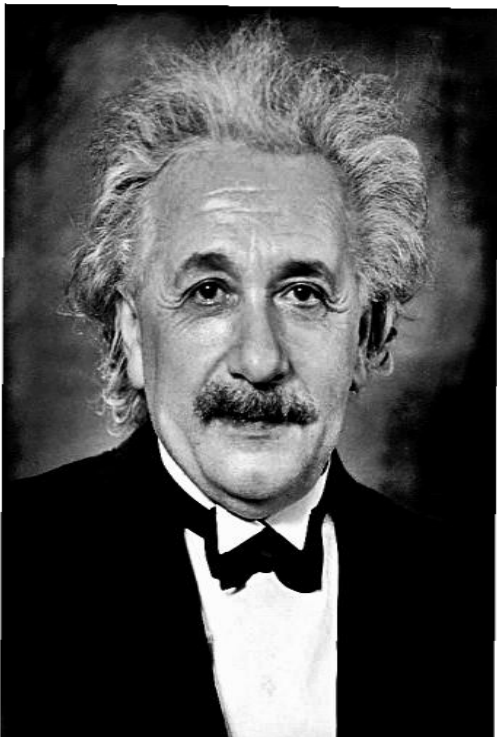
The result of his calculation was that *stars* with more than 1.4 to 3 times the mass of our Sun would be capable of collapsing into so called *Neutron Stars*. Beyond three solar masses, they will become *Black Holes* at the end of their life. With that calculation, the minimum possible mass was determined. Making use of the Schwarzschild formula, it was also possible to calculate the diameter of the smallest black hole imaginable.



Chandrasekhar was awarded the Nobel Prize for Physics very late in 1983 for his work. “Evolutionary Stages of Massive Stars“. Black holes were previously named Massive Stars (Wiki)

Some years before Chandrasekhar, **Albert Einstein** was engaged in studying the structure of space and time. He was interested in the behaviour of matter at high speed, the influence of matter on space and the essence of gravity. Einstein's greatest contribution to the world of Physics was his *Theory of Relativity*.

This theory determines the interaction amongst Matter, Space and Time, or what he called Space Time. It introduced gravitation as an attribute of Space-Time. He stated that massive objects cause a distortion in Space-Time, which is felt as gravity. He published his Theory Of General Relativity in 1915 and presented it to the Prussian Academy of Science. He also focused on the velocity of light which led to his Theory of Special Relativity. Along with the Theory of General Relativity, it came a new understanding of space and time and the meaning of “simultaneously”.



Albert Einstein was born 1879 in Ulm , Germany, died 1955 in Princeton, USA. He emigrated to U.S. during WWII and is an icon as a brilliant scientist and genius. He later used his popularity calling for peace and freedom and for understanding among Nations (Wiki)

One of his statements was concerning the speed of light: He noticed that the speed of light was independent of the motion of all observers. Countless experiments in later years confirmed that this theory was right. If that is true and the speed of light is indeed the limit, it is a natural barrier.

For instance, if the driver of a moving car switches on the headlamps, the speed of the moving car does not add to the speed of light as we would have expected in respect to the physics of Newton. The speed of light remains at c .

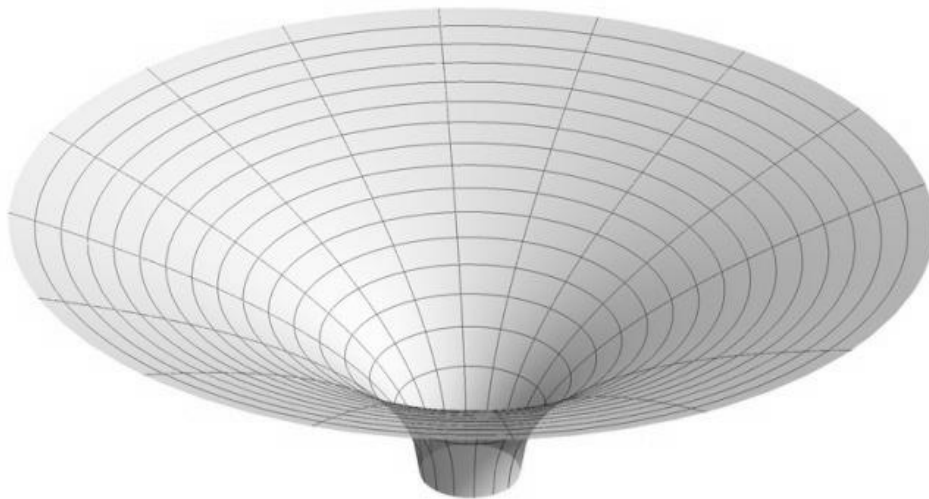


*The speed of light from an automobile headlight, will remain unchanged, regardless of how ever rapidly the car is travelling
(Photo R.Brückner)*

Again and again Einstein's theory was tested and found to be true. Particles with a speed exceeding that of light were postulated in vain. These particles had already acquired a name: Tachyons. They have *never* been found.

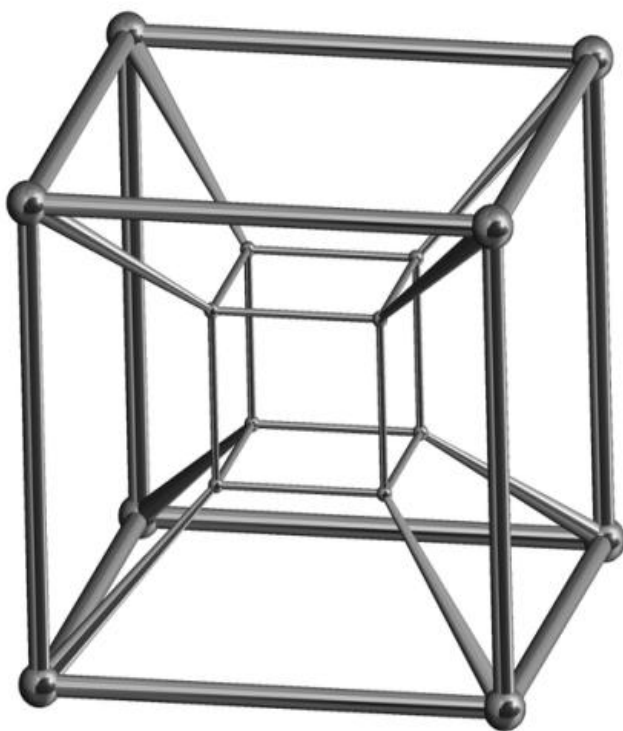
For Einstein, a black hole was a special case of a heavy mass causing a deformation or deflection of the Space-Time in the centre. The Theory of Relativity predicts a singularity in at the centre, under some circumstances. Some parameters go infinite if space is bent by the influence of a heavy mass.

Such parameters are the bending of space-time as well as the values for force, mass and time. Sometimes the bending of space-time is depicted by a picture similar to the one below. A large mass in the middle of the horn quasi will deform space-time. This means that in reality that space as well as time can bend or change. It can go so far that both will change over: time will become space and space will become time. It may be hard to believe or to imagine but is a consequence of Einstein's theories. Mathematics alone can describe such things accurately and completely.



For Einstein a black hole was the special case of a heavy mass causing deformation or deflection of space-time at the centre (Wiki)

Due to Einstein's Theory of Relativity, space and time can be regarded as having 4 dimensions, the so-called space-time. Space isn't linear, as we are accustomed to perceiving but it is curved because of the energy and matter involved in bending space. The dependencies among space, time, mass and energy gave birth to a new field of research called *Gravitational Physics*. Again black holes with their immense gravitational forces, come into focus.



*The Super Cube
Space and Time
have an
unexplained
relationship with at
least 4 dimensions.
(Wiki)*

One can even draw the space cube having 4 dimensions: Imagine that all corner points of the cube in the drawing are orthogonal *or at right angles* to each other. The drawing displays a cube having not only three dimensions but four.

Currently, Space-Time cannot be correctly defined, neither by the Theory of Relativity nor by Quantum Theory.

A further consequence of the Theory of Relativity is that world famous formula, $E=mc^2$. The formula shows how energy is equivalent to any mass. “Equivalent“ means that matter can appear either as mass or as energy in one form or another, e.g. light. With the help of this formula, both values can be converted.

This formula has immense significance in the interpretation of black holes. Whilst it's true that black holes have a great mass concentration, they also need to have great energy resources. Obviously, there is a lot of energy in a black hole.



$$E=Mc^2$$

The detonation of a hydrogen bomb (H-bomb) is a prime example of the conversion of mass into thermonuclear energy (Photo: Wiki).

An horrendous ramification of this formula is a nuclear weapon, the hydrogen (H) bomb. The explosion results from the action of Nuclear Fusion, a process involving the conversion of Hydrogen (the lightest element in the Atomic Table) to the next heavy element, Helium. This action occurs in stars and also of course, in the Sun, the result being the release of radiation and heat. We will have a closer look to that process in the chapter “The Birth of Stars“ because they are of a high relevance for black holes.

In addition to his Theory of General Relativity, Einstein presented his Theory of Special Relativity. The extension dealt with the motion of masses in space and time. That theory complements Newton's Laws of Motion (formulated 200 years before Einstein) in respect of the inertial system on which an observer is focusing .

Einstein stated that owing to the theory of Special Relativity, all physical laws in all inertial systems are the same. For instance, the speed of light will be the same in any inertial system. The consequence is that there is no fixed space and equally no absolute time. On the contrary, volume and time depend upon the motion of the object in respect to an observer's position. Both are changing, space and time. Both are variables. The only parameter which does *not* change is the velocity of light.

Before Einstein, a mathematician called **Minkowski** supposed that space and time were combined by what he called Continuum. His description of the mathematics involving the transformation of inertial motion systems became the trail-blazer for the Theory of Relativity.



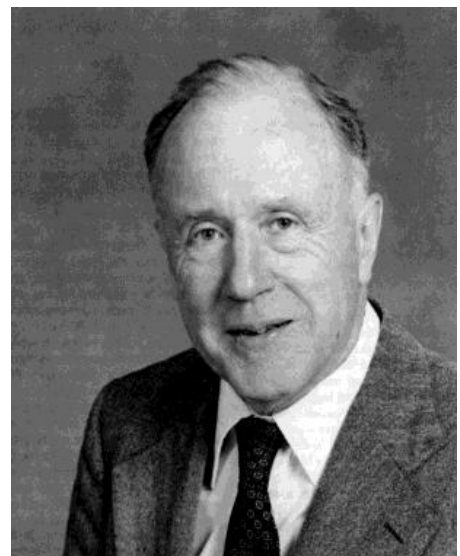
Hermann Minkowski, 1864-1909, was a trailblazer for Einstein's Theory of Relativity (Wiki)

The nomenclature “Black Hole“ was first used in 1967 when the American physicist **John Archibald Wheeler** from the American Space Agency NASA, gave a lecture at the Goddard Institute for Space Studies in New York.

At that conference one of the topics was the final stage of heavy, big stars, the so called Red Giants. Astrophysics states that stars do not live forever and that there is a definite end after some billions of years. How the end might appear was unknown at that time.

Red Giants usually gain a diameter about 25 times that of our Sun and are numerous in space, radiating deep red of course. It was clear from the red that the surface temperature had been lowered. The demise of such stars is full of drama: they do not fade away slowly but finally explode, ejecting their mantle. The remainder forms a small dense core which can become the centre of a black hole.

John Archibald Wheeler preferred not to use the expression “Heavy Frozen Stars“ so he accepted a proposal from an audience for the name “Black Hole“ (Wiki)



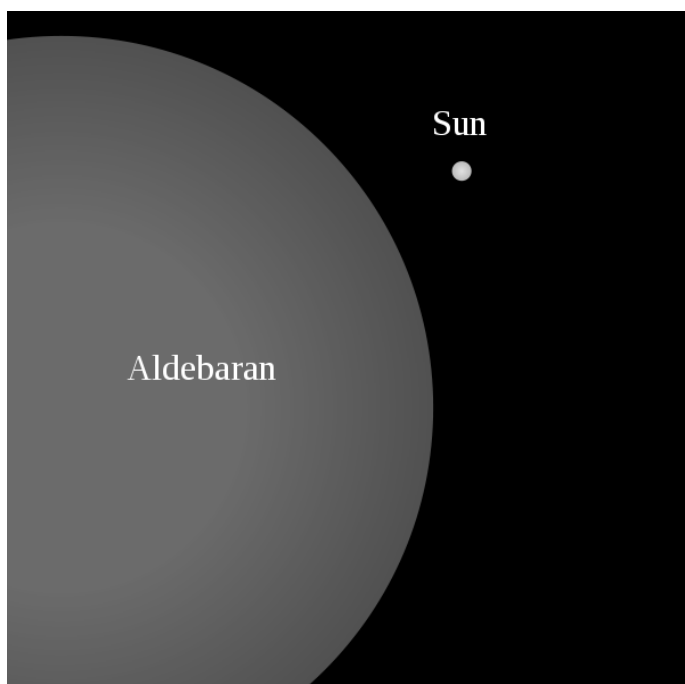
Participants at that conference described black holes as having 3 attributes: they are provided with mass, electrical charge, spin and nothing else. This caused Wheeler to make the statement: “Black holes do not have hairs“. The No-Hair theorem was born.

The term “Black Hole“ quickly spread because it clearly describes what remains after massive stars have exploded at the end of their life. The associated mechanism *is not yet fully understood*, even today.

- How can it be that the explosion of a star will effect precisely the opposite, i.e. under certain circumstances, an implosion?
- How many are there in space and what do they mean?
- Where and what they are?
- Why do they exist at all?

As always, Science creates more questions than answers. Each answer brings at least two new questions.

To understand the black hole, we first need to understand the physics of the Red Giants from which they emerge. For that reason we must look back to the beginning of time, to the birth of The Universe when all physical laws were established. It is likely that this also concerns stars and the rules they must follow.



A Red Giant named Aldebaran, seen here in comparison with our Sun. Eventually, this star will become a Black Hole (Wiki)

The Creation of The Universe

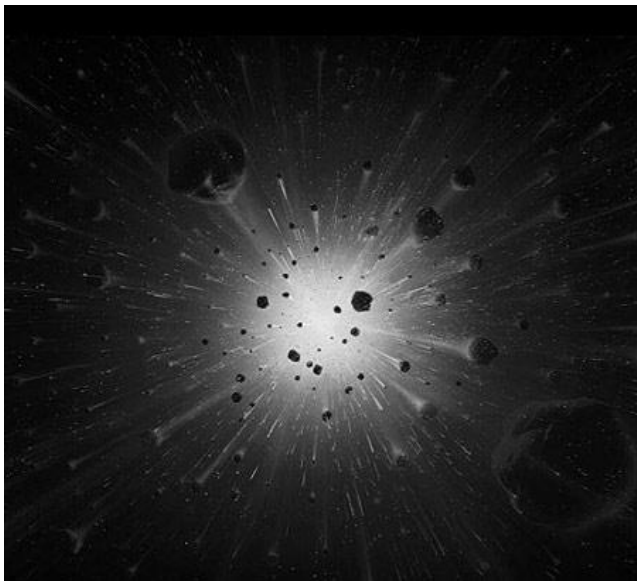


The Creation of Adam, painting by Michelangelo in the Sistine Chapel at the Vatican, Rome (Wiki)

It's quite interesting to study the different versions of Genesis. Every culture has one. The name Genesis means "origin". The creation of the world is described in an ancient Greek genesis, Gigantomachie which says that in the beginning there was *Chaos*. It matches *Galia* (the Earth), *Tartaros* (the Nether World) and *Uranos* (the sky) - All text sources are taken from the "Antikensammlung am Königsplatz", "The Antique Collection at Königsplatz" Munich. Presumably in that very first moment, matter existed in a chaotic form. Chaos means disorganisation and confusion.

In the first chapter of The Bible, Genesis states: "Then God commanded: Let there be light and there *was* light." A physicist might say, "In the beginning there was Energy" instead of using the word light. Famous physicist Hawking might say "In the beginning everything was information".

The old myth of the Creation of The Universe, is not at odds with the scientific knowledge which we may now have. On the contrary, the standard model of cosmology says that the Universe was created in a single moment, a certain point called the *Big Bang*. (This model isn't without its detractors). The Universe started from nothing and can be dated back 14 billion years. At that point, Space and Time began, as did the Laws of Nature which now regiment the entire Universe. The density of energy was very high, creating the high temperature of ions, the first particles. Molecules did not yet exist, nor even atoms. However, Space cooled quickly because of the rapid expansion and strangely, this expansion seems to continue today and is accelerating.



*An Artist's
impression of the
Big Bang (Wiki)*

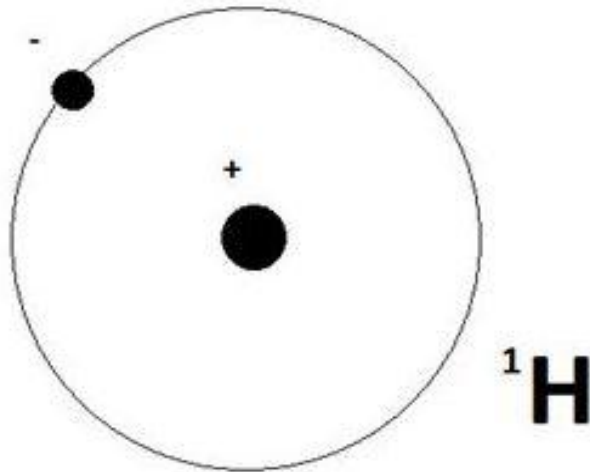
In the late 20th in the last century, **Edwin Hubble** discovered a relationship between the distance of galaxies and the so called Red Shift of light. For astronomers the Red Shift was proof of the expansion of the universe and also proved both its acceleration and the theory of the Big Bang. This permanent expansion and the existence of black holes is one of the deepest secrets of the Universe.

The Birth of Stars

In the very beginning, only the element *Hydrogen H* existed. It didn't take the form which we understand on Earth today but a form known as 'Plasma'. These clouds of plasma expanded and cooled rapidly, the hot and glowing, red clouds beginning to fill the vacuum. They are situated in the so called H-II regions (say H Two) in Space. Plasma means, that the two components of hydrogen, the proton and the electron, had not yet combined into elementary hydrogen. Enormous heat prevented the forces of attraction from bringing them together as an atom. In such an extreme environment with matter in this state, the hydrogen is known as "ionized". Hydrogen's particles can fly freely in space where-ever they choose. Under these conditions, the gas no longer has any electrical resistance, the situation being reproduced under laboratory conditions for the first time in 1996. The gas became a superb conductor, in which state hydrogen is known as "Metallic" hydrogen. It therefore follows that high currents can flow and equally, *strong* magnetic fields can be formed. Crucially, to the later birth of stars, is that these clouds of ionized hydrogen were present in different densities in space. These places later became the stellar nurseries of Stars.



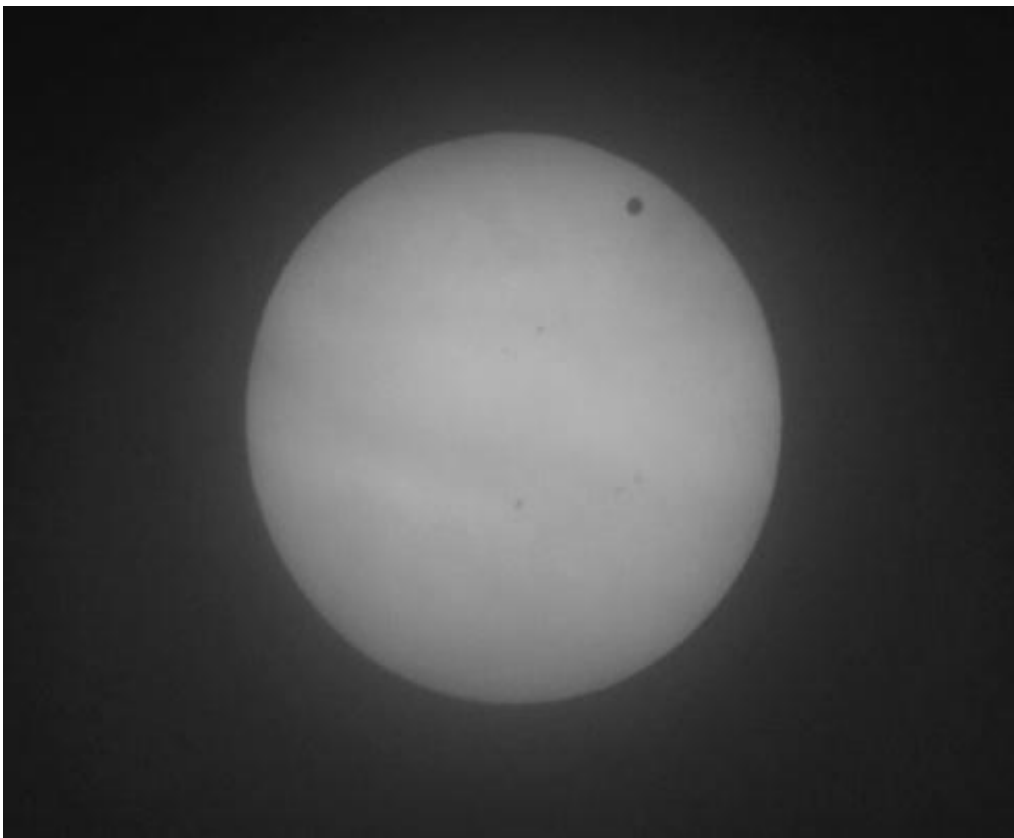
*The open star cluster,
Messier object M45
called "Pleiades" or
"The Seven Sisters
(picture taken by
amateurs of VSW Munich
in 2013)*



*The Atomic hydrogen (${}^1\text{H}$) is **the** most flimsy of all of the known 93 natural elements. It consists of a proton encircled/orbited by an electron*

When space temperatures were sinking and plasma ceasing, electrons, no longer held apart from protons, could now be captured one by one, by those waiting protons, building an elementary hydrogen molecule H-I (said H One). This very process can still be detected today, with the help of Radio Telescopes. The radio emission of H-I clouds radiates at a wavelength of 21 cm and is a pointer to regions where stars are being formed. Clouds expanded ever more & with the lower temperatures, the molecules which we know on earth were formed: the so called H_2 appeared. This molecule is the forerunner of the even more famous H_2O , water which is well known as the basis of life. Pure hydrogen H_2 the lightest element, was used for lifting the Zeppelins in former years. (Unfortunately it is highly inflammable). Gravity started to control the huge clouds formed by hydrogen, re-condensing the clouds further, causing sudden rise in pressure and temperature. Stellar nuclear fusion was researched by **Robert Atkinson**, **Ernest Rutherford** and **Hans Bethe**, amongst others.

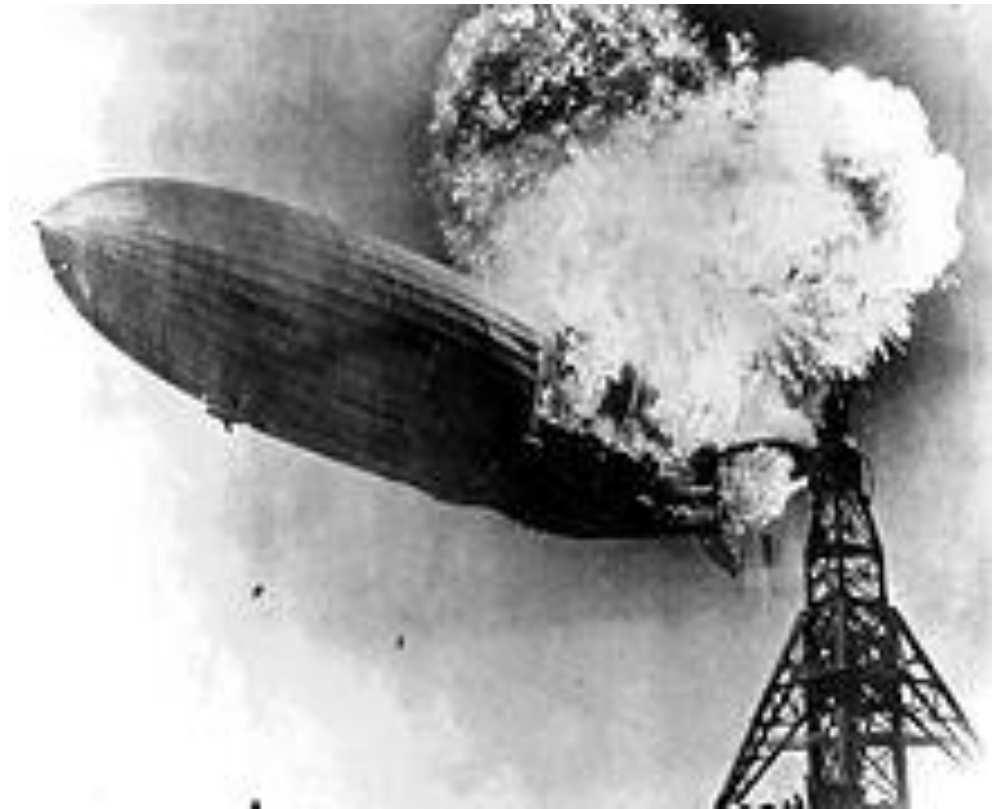
When temperatures reached approx. 15 million degrees Celsius, a complex process started. Suddenly, the transformation of two hydrogen atoms into a helium atom with the help of two neutrons began. Fulminating stars occurred, radiating everywhere in space, by a process in the name of *Nuclear Fusion*. By the laws of Physics, helium is slightly lighter than the 2 hydrogen atoms plus the 2 neutrons from which it is constructed. Therefore some mass is missing. Einstein's formula $E = mc^2$ accounts for this. The missing mass is converted into pure energy as in The Sun. This energy can be seen as light but also there are other components released, occurring as heat and ultra-violet radiation, quite invisible to human eyes.



*An example for Nuclear Fusion is The Sun
The transit of Venus across the face of the Sun in June 6,
2012. The planet Venus is to be seen as a small black dot in
the upper right corner of the picture (taken by : R.Brückner)*

The name Helium comes from the Greek word Helios which means “sun” and was discovered relatively late – compared with the other 92 elements, by the French astronomer **Jules Janssen** who had joined a scientific expedition in India in 1868 to study a total Solar Eclipse. For the very first time, a new element was found, not on Earth but out in space.

Here on Earth, the inert gas helium is used in gas glow lamps and also in airships like the Zeppelin, this because of the fact that helium is lighter than air. It will ascend until it reaches a certain altitude. For that reason and because it will not burn, helium is a perfect lifting gas for airships. In former times the highly inflammable gas hydrogen was used for filling airships – once with drastic consequences.



The Hindenburg disaster: The famous picture of the tragic burning of “Hindenburg” in 1937. The German passenger airship had just arrived in Lakehurst close to New York. Of the 97 people on board, there were 35 fatalities (Wiki)

We have learned that the basic element hydrogen, was formed the stars approx. 400 million years after the Big Bang. This process is ongoing but reached its climax about 4 - 6 billion years ago. At that time, our own Sun was formed. The birth of suns is still not finished. It *can* be stated simply that suns are really huge ovens fired by Nuclear Fusion. This means that hydrogen will be converted into helium with the emission of light, heat and other forms of electromagnetic radiation. Stars usually aggregate in the form of star clusters. Such star clusters belong to the oldest formations in the celestial sky and are a favourite target for telescopes of many Astronomers.

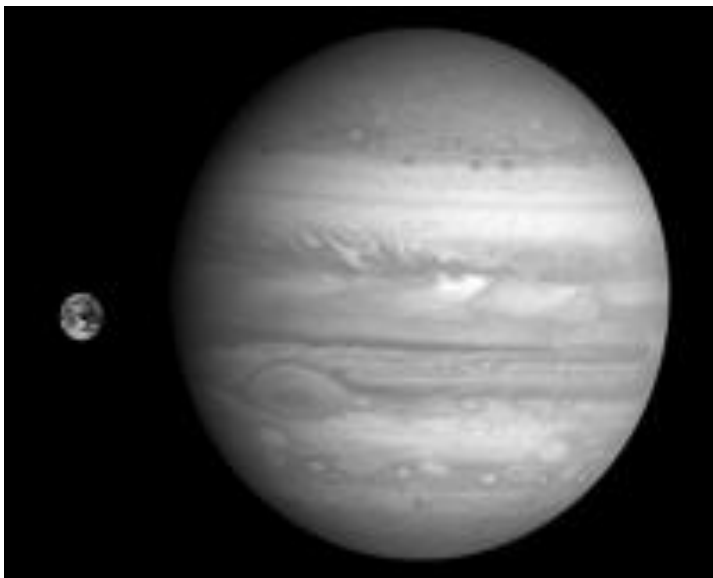


The star cluster M13 in the configuration Hercules, is one of the most beautiful in the Northern Hemisphere, newly created, closely following the Big Bang. Its distance from us is approximately 25,000 light years and it comprises thousands of stars like our Sun – Picture taken by Martin Elsässer of VSW Munich

Stars do not solely burn hydrogen into helium but are also able to create further, heavier elements. In so doing, step by step, all of the 92 known elements were built. This includes Carbon, the element with which humans and all organisms are formed. However, the elements which form our planet and support life on it, did not originate in The Sun. It is too young. The carbon came from earlier stars at the formation of space, further back in time than when the Sun and planets of our Solar System were being assembled. It can be stated categorically that humans are derived from “Star Dust” which means hydrogen. The electromagnetic radiation of the Sun appears in the form of light and heat at about 1000 watts per square metre. It also contains radiation in all forms of electromagnetic waves e.g. radio waves, ultraviolet light, throughout the spectrum, to include X-Ray and Gamma Rays. Medical science reveals that electromagnetic rays with wave lengths of kilometres and metres, as used by Radio and TV Stations and even mobile radios/phones are *not* harmful to humans nor animals.

However, the shorter the wavelength, the greater the hazard and so with increasing frequency, (because wavelength and frequency are reciprocal) a critical limit is reached and the threat of skin cancer looms. The threat of carcinoma increases, the shorter the wavelength becomes. A dangerous type of radiation is ultraviolet rays from the Sun. Fortunately, the atmosphere over our head protects us by absorbing this dangerous radiation. Despite that, the atmosphere is very thin, just 30 kilometers. We still need to take care against exposure to UV radiation.

According to the Big Bang theory, the expanding Universe cooled to 10 degrees Kelvin, corresponding to approximately minus 263 degrees Celsius. Gravitational forces gathered dust around The Sun, more and more. Planets were formed. A planet – in contrast to a Sun – does *not* radiate. As its mass is too low, fusion cannot occur. An excellent example of such a planet failing to achieve the status of sun, we can see in our own solar system. It is the planet Jupiter, containing approx 1/80 of the mass of our Sun. The constituents are mainly pure hydrogen with other forms of gas like methane, ammonia etc. This means, Jupiter has no hard surface as does Earth but a soft one. It is a gas planet.



*Comparison of
Earth (left) and
Jupiter (right) - Wiki*

If Jupiter had become slightly heavier, the process of fusion would have commenced in its interior. In that case we would now have two Suns in the sky with all the inevitable consequences, one of them being that there would hardly be any night. Binary systems having two stars are not rare in space. Even systems with three or four stars can often be found.

*The binary stars Cor Caroli,
bound together by
gravitation. Positions in
2013 will be different
because of the high velocity
of the companion star.
Picture taken by the author
in 2010*



Binary and triple systems are popular subjects for the telescopes of astronomers. They were detected easily, even in bad viewing conditions from cities, and are easy to capture on camera. There is a certain fascination in so doing at widely separated time intervals and then to observe the movements of the stars in their positions, respective to each other.

The aggregation of matter was observed for the first time aboard the International Space Station ISS in 2013. An astronaut conducted an experiment allowing flour and powdered sugar to float in a glass container. He was able to observe and document how particles aggregated under the influence of gravity. Tufts of dust formed like snowflakes within the glass container. It can be assumed that the same laws causing these, also came into play in space, creating similar ‘tufts’ of interstellar matter and consequently planets and suns. The kinetic energy generated by the power of the Big Bang led to a common direction of motion around a common centre, appearing as a disc from a distance. In consequence, all planets are in the same plane orbiting their sun. Suns having planets, seem to be the standard configuration in the Universe. For some years now, hundreds of them have been detected. Detection is not easy because planets are relatively dark compared to their sun. They can be detected by a method known as spectral shift.

In 1995 a planet outside our Solar System was first discovered by **Michael Mayor** and **Didier Queloz** at the University of Geneva. The *exoplanet* is called *51 Pegasi b* and orbits its sun in four of our days. This big planet is situated in the constellation Pegasus, at a distance of approx. 40 light-years. These kinds of planets also are called “Hot Jupiters“. It is a class of planets having the size of our Jupiter, heated extensively from its sun by virtue of close orbit. In successive years, hundreds of exoplanets of various sizes were discovered and in many constellations, being almost invisible and difficult to detect. For that reason, detection was not carried out using standard techniques, i.e. optical telescopes but by analysing the spectral lines of the central suns whose lines are shifted by the influence of the orbiting planets. Nowadays almost every sun is expected to have planets in orbit.

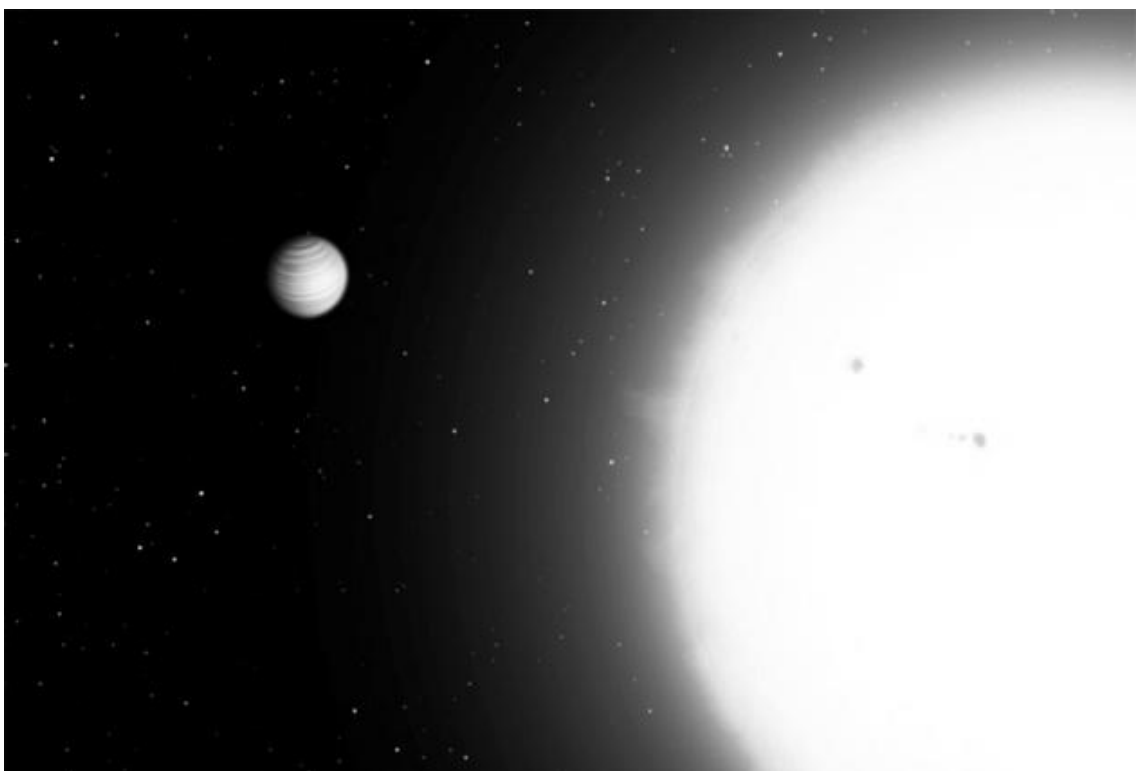
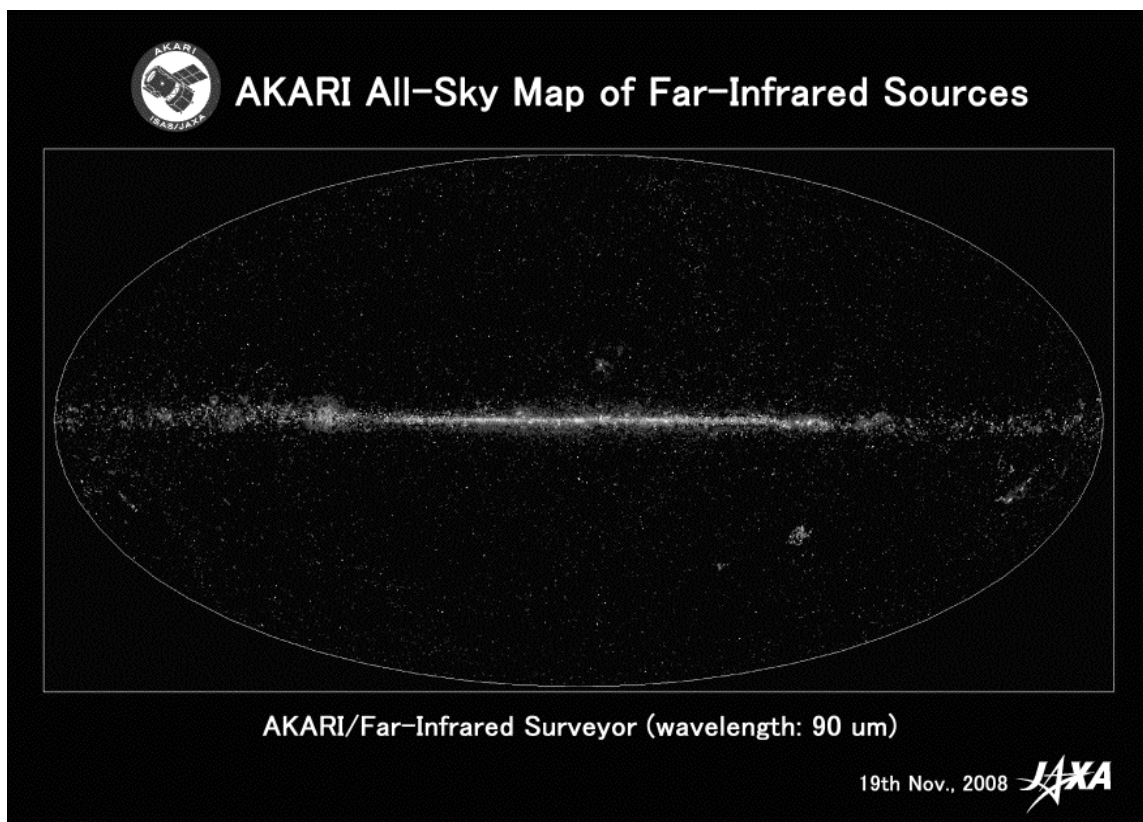


Illustration of the exoplanet 51 Pegasi b. It can't be exposed on an image because it's too close to its sun. The contrast between them is far too great (Wiki)

The birth of stars in our Galaxy is not yet finished, probably not in the entire Universe. There are areas where stars continue to be formed. Infrared cameras are well suited for taking pictures of such H-II regions because they glow in red and further, in ranges, invisible to the human eye. The camera on board a satellite like “Akari” is capable of rendering such regions quite visible.



This infrared picture of the Universe was taken from the Japanese satellite AKARI. Pictured is our Milky Way and the bright regions are areas where stars are formed (By courtesy of JAXA)

One of the most beautiful regions forming stars is situated close to us in the Milky Way, just 1300 light-years distance . It is within the constellation of Orion, appearing during winter in the Northern Hemisphere. There is a big glowing nebula, visible to the naked eye, just at the centre of that configuration. (See next page)



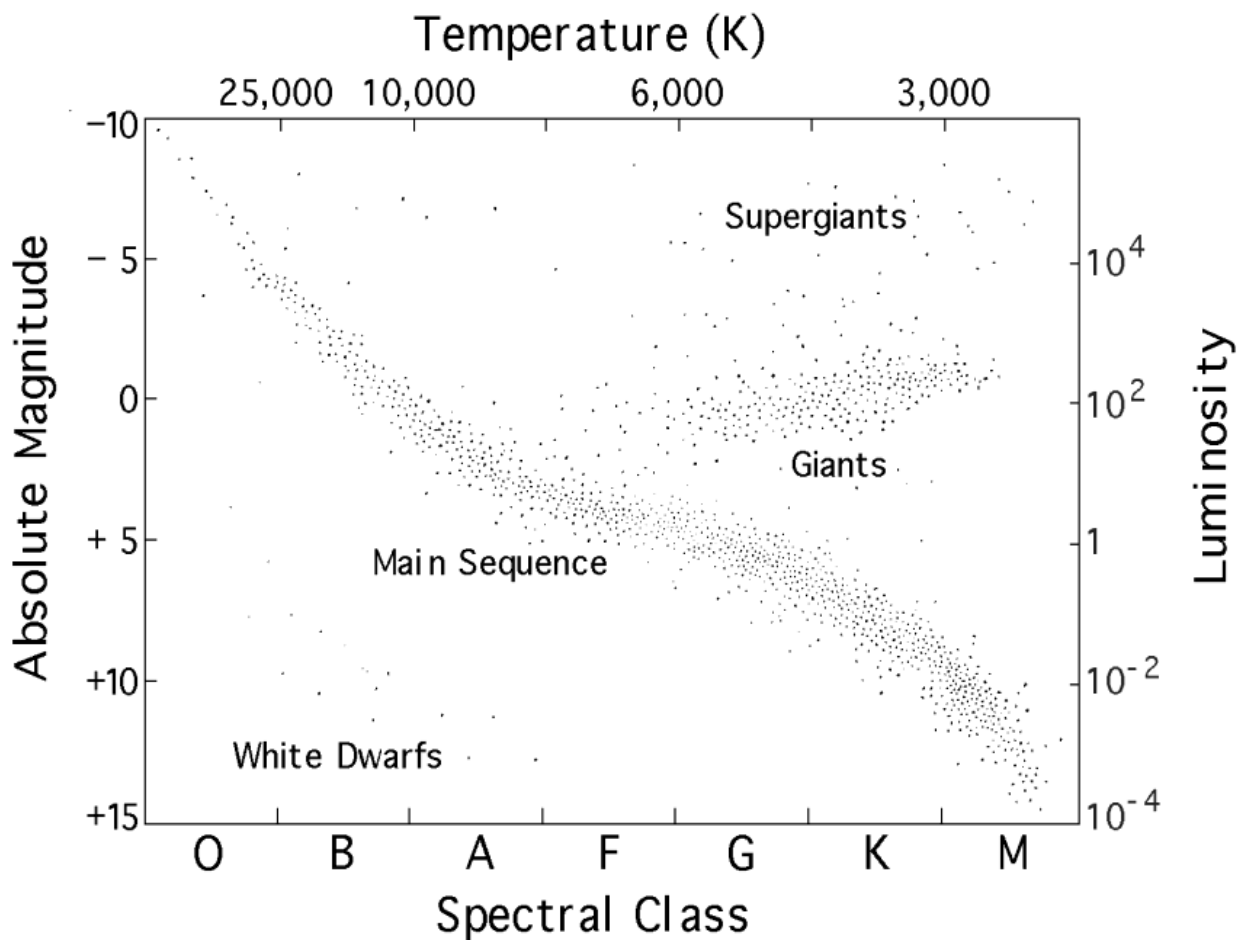
The Great Orion Nebula M42, which can be seen with the naked eye, looking like a foggy spot in space, just giving birth to stars. With your binoculars, take a look to the South-East on a moonless winter night. (picture taken by amateurs of the VSW Munich)

We can summarize:

- In the beginning was the Big Bang.
- The first element was hydrogen
- Clouds of hydrogen appeared and aggregated in H-II regions
- After that the formation of stars began

Stars have different sizes because of the different mass of hydrogen which was distributed initially at random in the Universe. Big stars are mostly red and of immense size, leading to their name, Red Giants. Smaller stars are more in white or blue but they do not remain within the same spectral class forever. They may change their colour with time and hence are able to change their spectral class.

Apropos black holes, we have to focus on the Red Giants because of their relevance. A useful aid to understanding the life cycle of the stars is the so called “Hertzsprung-Russell diagram“ devised as early as 1910. These diagrams - also abbreviated HRD – are not maps of the locations of the stars in the Milky Way. In HRDs, the brightness of stars is plotted against their colours or temperature. Temperature is proportional to colour and is measured in degrees Kelvin which is roughly the same as Celsius. Please note that most stars appear in a line from up left to down right.

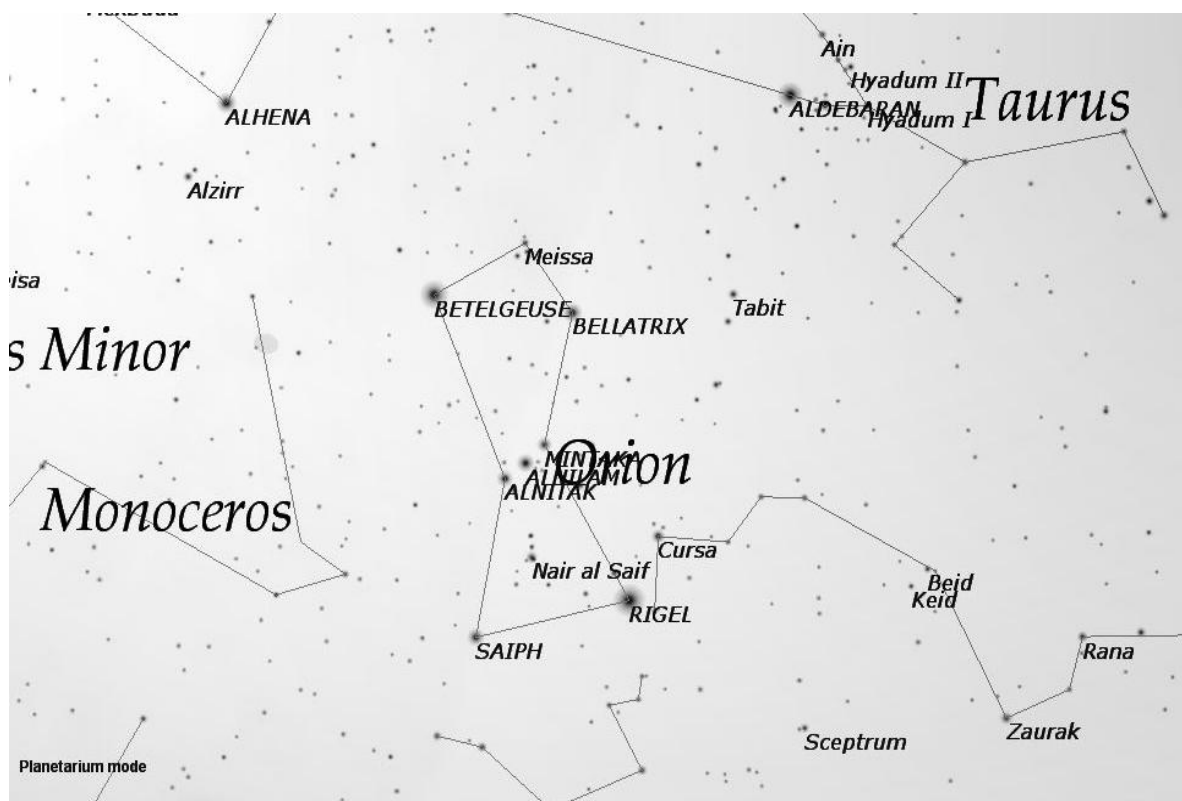


The Stellar classification is very old: 200 years ago astronomers had started to distinguish stars by colour in seven spectral classes. 99% of all stars are included in the Havard classification. They are named using the Latin alphabet O,B,A,F,G,K,M. For students, the sequence can be memorized as “**O Be A Fine Girl Kiss Me**”.

Red Giants belong mostly to the spectral class K and M, and the temperatures on their surfaces are from about 3330 to 4750 degrees Celsius. The two classes F and G represent White Stars of medium size, including our Sun. The Sun is an average star with a surface temperature of about 5000 – 6000 degress Celsius. The classes O, B and A stand for small stars with blue spectra and a hot surface more than 10,000 degrees Celsius.

How to find Red Giants?

Red Giants are stars very much bigger than The Sun and are very common in space, being easy to detect by the red light from which they are named. For instance, Betelgeuse in the star configuration Orion is one. It is a star having about the 20 times the mass of The Sun, at a distance of approx. 600 light years. *Betelgeuse* is easy to find, again owing to its brightness and red colour at top left in that constellation. Orion was the name of an ancient hero and warrior in Greek history. In the star chart is another Red Giant, *Aldebaran* in the constellation, Taurus (see also page 38).



One Red Giant is the star Betelgeuse, in the star configuration Orion (map generated using the program WinStars)

Famous Red Giants in our celestial neighbourhood are beside Betelgeuse and Aldebaran, the Arkturus, Antares, Eta Carinae and many more.

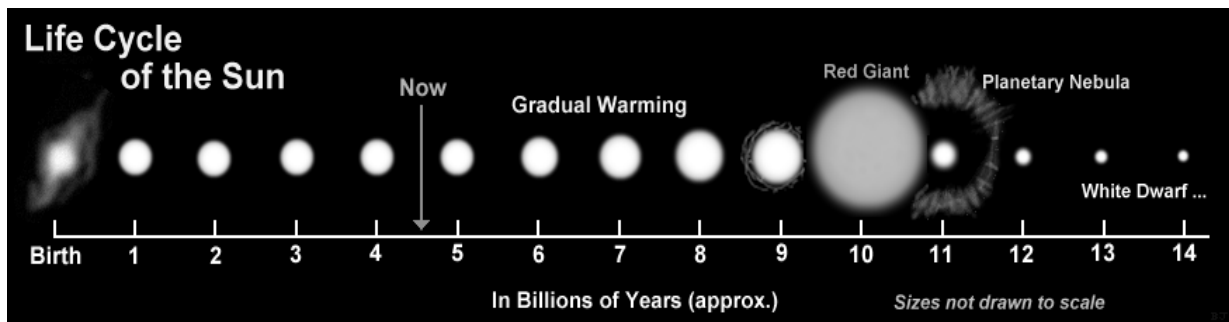
The Blue Stragglers:

Giants Stars are not always red. They can be also blue. The first to observe them was an Astronomer named A. Sandage who in 1953, shot photos of the star cluster M3. It transpired that some hot stars shone with an intense blue. They seemed to be young, much younger than the rest of the star cluster M3 itself which generally is very old as described on previous pages. This characteristic gave a name to this kind of young stars: *stragglers*, because they appeared much later than the rest of the cluster. (see p.45). Blue Stragglers seem to be atypical in many ways. Color, age and intensity remained a mystery for many years. Today, astronomers suspect them to be the result of a collision of a binary system in the dense core at the middle of a star cluster. Presumably the collision of two stars in class A and B can create another star of class O. The temperature on the surface of the newly formed stars rises to 100,000 degrees Celsius causing them to radiate *blue light*. Blue stragglers are also anticipated to become black holes because of their immense increase in mass at the collision. They might even become black holes immediately after the collision. It depends upon the mass which the involved participants contained before the collision. This confirms that the birth of stars in The Universe is not yet finished and also reminds us that The Universe is not constant, but continues in a process of change and mutation into a state previously non existent.

The End of the Stars

What will eventually happen to our Sun, which is an ordinary medium sized star of spectral class G? Its age is about five billion years. The luminosity of a star is not constant. Our Sun is gaining size steadily as do all stars and becoming brighter in the process. At the end of its life time (which is expected to be approx. another 5 billion years from now) the Sun will become bigger and bigger and shift in colour to red. Its size will continue to increase, becoming a Red Giant and will explode at the end. This happens when the hydrogen fuel is exhausted, bringing to a halt the fusion process. All atoms of hydrogen inside have been converted into helium and other (heavier) elements. After a certain period of time (relatively short compared with its life time as a whole) the Sun will collapse and unhorse its mantle in an explosion. A so called *Planetary Nebula*, formed from the smoke of the explosion and the remnants of the fusion process, will appear. This mantle contains not just helium but also the other, more heavier elements. The remainder of the star will concentrate and condense into a small core called a *White Dwarf*. When the Sun becomes a White Dwarf, it will cool and shrink., eventually being only a few thousands miles in diameter. No *further* nuclear reactions can take place and the faint star radiates its residual heat into space becoming cold and dark – a *Black Dwarf*. That really is the end.

It's all over. Really? We must accept that there *is* an end for stars but not for the elementary particles of which they are composed.



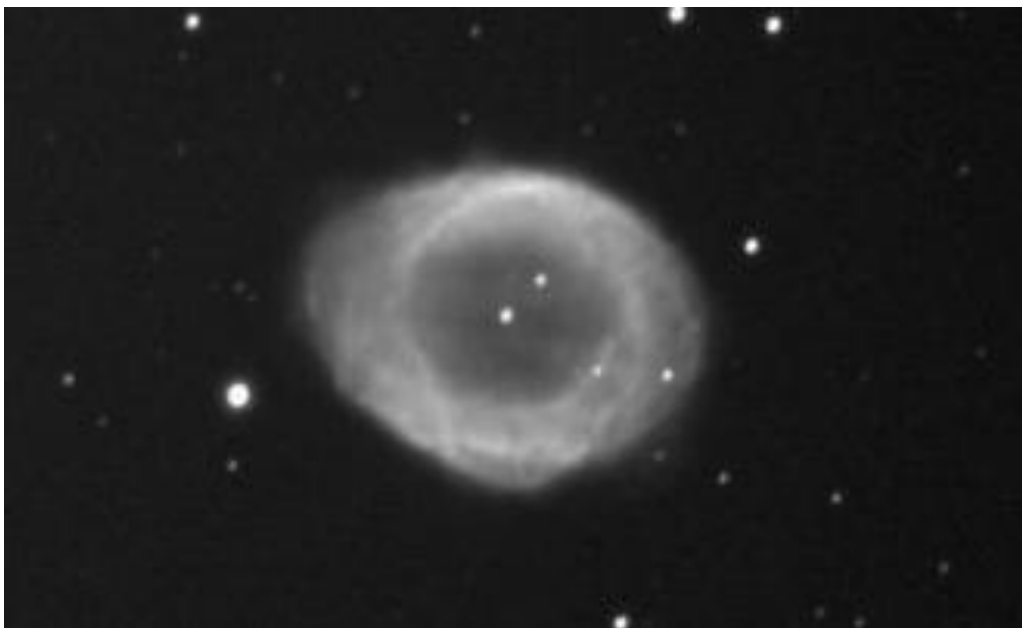
The solar life cycle of our Sun (Wikimedia)

There is no “end“ for interstellar matter, in the proper sense of the word because the fundamental particles will exist in perpetuity.

It is crucial what mass the stars had at the outset of their life. The starting mass is a criterion for its brightness during life, its duration of life and also for its destiny. Stars having the mass of the Sun, will become Red Giants and form a colourful planetary nebula when life is over (see illustration on that page). Stars greater than our Sun is will form a *Red Super Giant* and finish in a big explosion called a Nova or *Super Nova*. This is a stellar explosion which contains more energy than the star could be expected to emit during its entire life span. The explosion expels much or all of a star’s material for days or even weeks. Nova means “new“ in Latin, referring to what appears to be a very bright, new star shining in the celestial sphere. The expanding shock waves from Supernova explosions can trigger the formation of new stars and produce *Neutron Stars* or *Black Holes* at the centre. So far we have learned that a black hole is part of the final stage in the lifetime of huge stars called Red Giants.

Smaller Suns form a Planetary Nebula:

Smaller stars like our Sun will form a planetary nebula at a certain phase of their life-time. They consist of an expanding glowing shell of ionized gas, ejected from Red Giants late in their lives. The word nebula is Latin and means mist or cloud and describes what can be seen at certain points in the celestial sky. Time exposures show marvellous colours and bizarre forms from which they get their names. Famous planetary nebulae are the so-called Cat's Eye Nebula, Helix Nebula or Eskimo Nebula. For astronomers, they number the most watched objects in the celestial sky. They require a dark sky and large telescopes with high magnification in order for the faint objects to be seen. Sometimes a small star can be seen in the centre, a legacy called a White Dwarf. One very famous planetary nebula is the Ring Nebula M57 in the star configuration Lyra. Sometimes in good viewing conditions the *centre star* also can be seen.



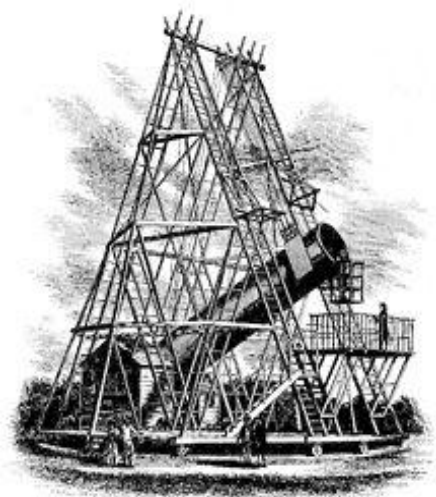
*The famous Ring Nebula (M57) in the star constellation Lyra
(Picture taken by Martin Elsässer of the VSW Munich,
52x2min using ISO 800)*



Wilhelm Herschel, 1783-1822, was an Hanoverian-born British Astronomer and Composer (Wiki)

The first to recognise these celestial objects was **Wilhelm Herschel**, a British-German astronomer of more than 200 years ago. He looked for the planet Uranus, predicted but not yet found. Herschel recognised many objects looking through his big telescope in Datchet in Berkshire (UK). Herschel thought the objects were stars surrounded by material that was condensing into planets. That was *not* so. Planetary Nebulae have no connection with planets, as we have seen previously. However, Herschels General Catalogue of Nebulae and Clusters from 1864 is still in use, supplemented with discoveries from many others and published 1888 under the name “New General Catalogue“ containing thousands of deep sky objects. Most of these objects are of relevance to black holes.

Herschel constructed the largest reflecting telescope with a 50cm primary mirror and 12m focal length! A reconstruction can be admired at the Royal Observatory in Greenwich





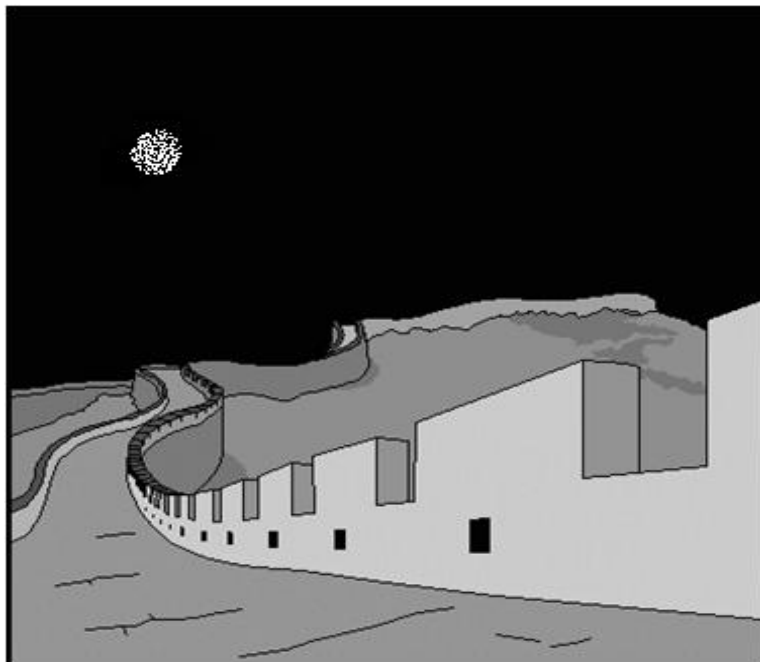
*Charles Messier,
1730 – 1817, French
Astronomer*

Charles Messier actually was a comet hunter and a contemporary of Herschel. Making his observations in Paris, he also noticed many remarkable misty objects in the celestial sky which he felt couldn't be comets. Unlike comets, this nebula did not move through the night sky. He noted the positions of 103 objects, which was the beginning of a famous list to which he gave his name, the Messier catalogue. His final version published in 1781, contained planetary nebulae, open and closed star clusters and remains of supernova explosions.

For a many years, the catalogues of Messier and Herschel were a boon for astronomers. Late in the 19th Century, finally the secrets of these celestial objects were beginning to be revealed. Nobody had yet reached the conclusion, that there must be some connection between the existence of massive stars having immense gravity (as John Michell had predicted) and those misty objects in the night sky.

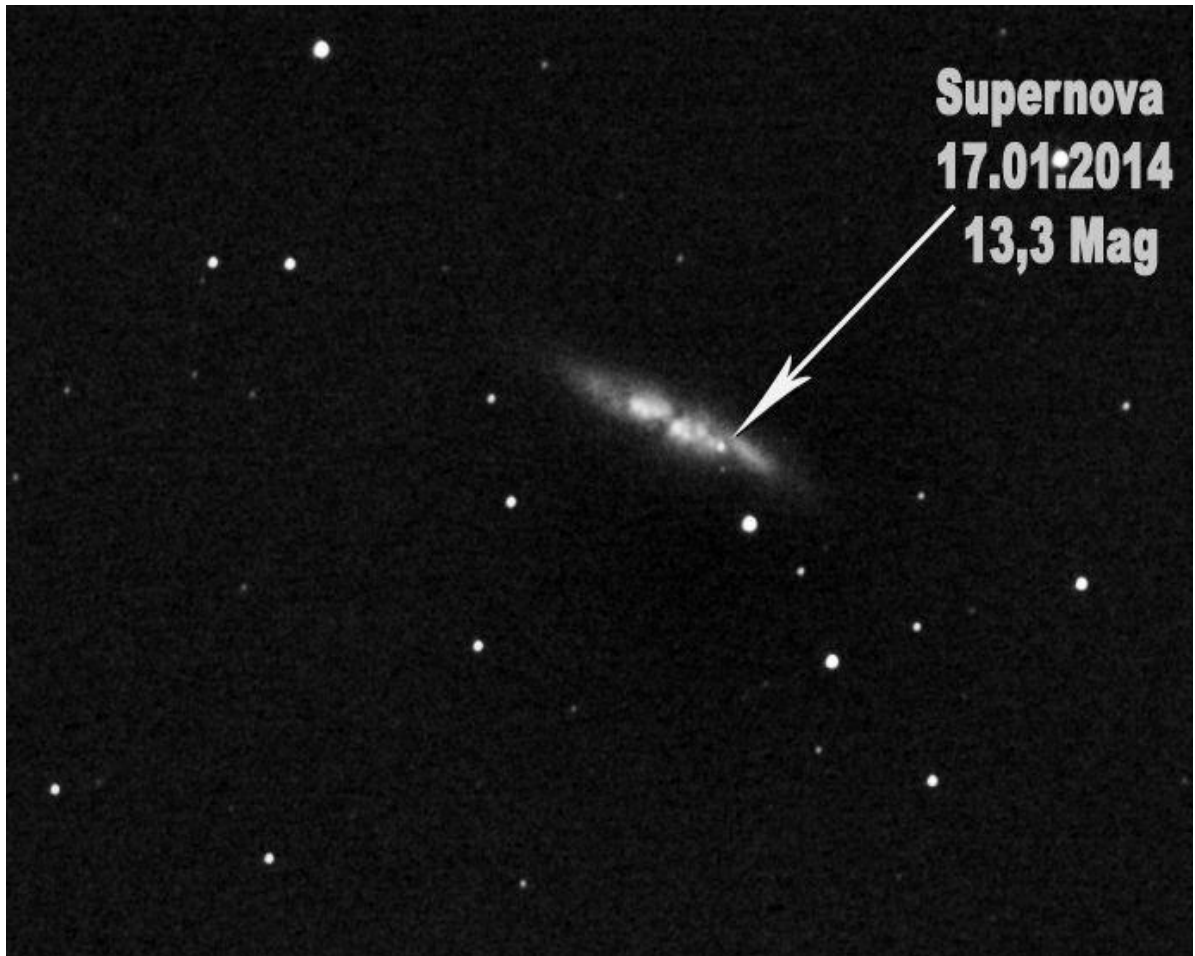
Some Stars end as a Supernovae:

Since Schwarzschild, Chandrasekhar et al. it became clear, that the process of transformation of big stars will be different to that of our (small) Sun. They will form red giants which explode at the end of their life time, becoming **supernovae**, the pre-stage of black holes. Almost every year one appears in a Galaxy. The first characteristic is the sudden appearance of a new bright spot in the sky, never seen before. The first supernova noted was by Chinese astronomers and also by a monk in Belgium, in 1054, within the constellation, Taurus. This was a very bright event, possibly visible even in day light. The pale afterglow of the event is still to be seen in that star configuration and looks like a crab giving the name “Crab Nebula“. It was number ONE in Messier’s ”Catalogue of Nebulae and Star Clusters” starting with M1 and ending with M103.



First appearance of a Supernova reported by Chinese astronomers in 1054, visible as M1 as the so called Crab Nebula in the constellation Taurus (artist´s impression)

There are supernova explosions so strong that they can even be seen in other galaxies. This happened for instance, in January 2014 when a supernova appeared suddenly in the galaxy M82, see photo below. It was taken by Herr Elsner. He was one of the first reporting to the IAU immediately.



*Superb picture of a brand-new Supernova in the M82-Galaxy
(picture taken by Ronny Elsner, using a 4" Astrograf,
10x30sec, ISO400, EOS1000Da)*

If there were to be any supernova appearing in our own galaxy (the Milky Way) such an event could even jeopardize life on earth. Supernovae radiate not exclusively visible light but also in the entire, invisible spectrum of electromagnetism, e.g. X-rays and Gamma rays, ranking amongst the most dangerous radiation of all.

As it is generally known, Dinosaurs became extinct about 65 million years ago. Before that, they had lived for more than 200 million years and were the dominant species on earth. How could that suddenly come to an end? Were they killed by a Supernova explosion or by the impact of a big meteor strike?



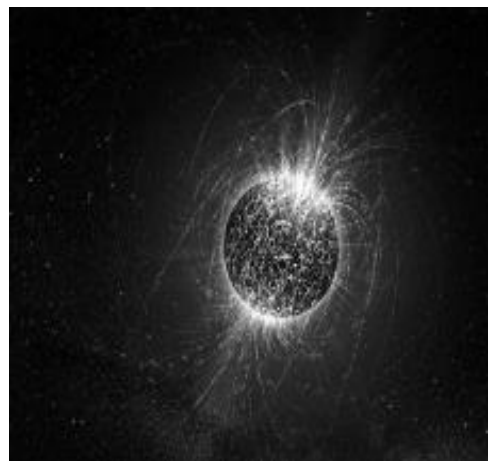
*Mass mortality
of dinosaurs
approx. 65
million years ago
(Wikipedia)*

The standard theory is that it was either a meteor strike or an asteroid strike which caused them to disappear from the face of the earth, as well as the many other species which also suffered extinction. Some smaller animals plus animals living in the sea tended to survive, e.g. crocodiles. The water protected them. Another plausible explanation would be the explosion of a supernova close to earth. There is no shock wave emanating from a supernova explosion but pure energy in the form of highly energetic electromagnetic radiation, mostly invisible, endangering flora and fauna. It is *Gamma*-and *X-rays* caused by super massive Black Holes which might wipe out life. Fortunately such Gamma Ray Bursts (GRB) do not happen so often in outer space. Just once in a hundred years in every Galaxy is there such an event. On the whole, it is not a rare event, because there are billions of Galaxies in the Universe.

The Neutron Star:

Even such a remarkable event as the explosion of a supernova, will come to an end, and surprisingly quickly. After the diminution of light and other forms of electromagnetic radiation, there will be nothing more to be seen, within months or years. Not very much is left of the former Red Giant. When the star's fusion process has ceased and it has collapsed after a big explosion, the remaining matter will be reflected by its own mantle, returning to the core. The direction of radiation is reversed, resulting in a small and dense core of highly compressed matter, the size of just a few kilometers. In such a way, a new strange stellar object is born, a fast rotating neutron star. It is one of the celestial objects with extraordinary properties because of the high concentration of matter in that tiny core. The density is so immense that a spoonful of the matter from a Neutron star would have the weight of approx. 10 million tons. It consists solely of neutrons. Hence its name. Such Neutron stars also have so called "jets" at their poles, radiating Gamma- and X-rays.

Fast rotating neutron star, the pre-stage of a black hole having abnormal characteristics and behaviour. (An artist's impression, Wikipedia)



The conditions within the neutron stars are quiet abnormal – having a state which just does not exist on earth. Nor can scientists create such conditions, in a lab

As opposed to black holes, Neutron stars *can* be viewed in the heavens by astronomers.

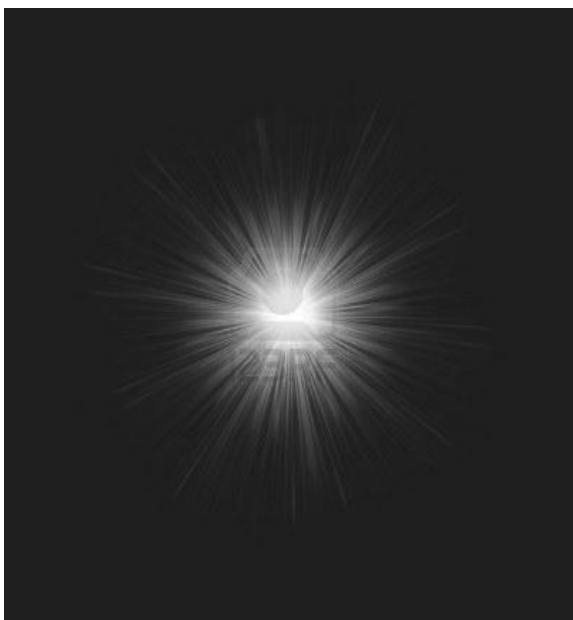
The space photo on this page was taken in 2013, showing a star cluster in our Milky Way, 47 Tucanae. Star clusters are an accumulation of stars which are the oldest objects in the Celestial sky. They can even be detected in other Galaxies having the same age as the rest of the Universe, approx. 13 billion years. Because star clusters are so old, many of their stars have already completed their life time and become neutron stars. They have been identified within 47 Tucanae but in addition, black holes are confirmed in other star clusters (see page 55 “Blue Stragglers“).



*This star cluster 47 Tucanae emitting X-rays, verified to
have countless Neutron Stars
(By courtesy of NASA/CXC/Michigan State/A.Steiner)*

Research into a special Neutron star within the star cluster 47 Tucanae, recently carried out by astronomers revealed and confirmed that there is a relationship between the size and mass of a neutron star, just as predicted by Chandrasekhar (see page 28). The understanding of the neutron stars is a pre-requisite for the understanding of black holes. Bear in mind that if the neutron star were marginally larger in mass, it would itself have become a black hole with quite different physical qualities.

Furthermore, scientists have demonstrated that the average neutron star within a constellation has about one and a half times the mass of the Sun. In contrast to the Sun, its diameter is only 12 km. That is the size of a minor city. Because the density of the core matter is so high, an ideal sphere, which has pressure ten million to a billion times higher than that pressure needed to form diamonds on Earth, would have “mountains“ on its surface not exceeding 5 millimeters.



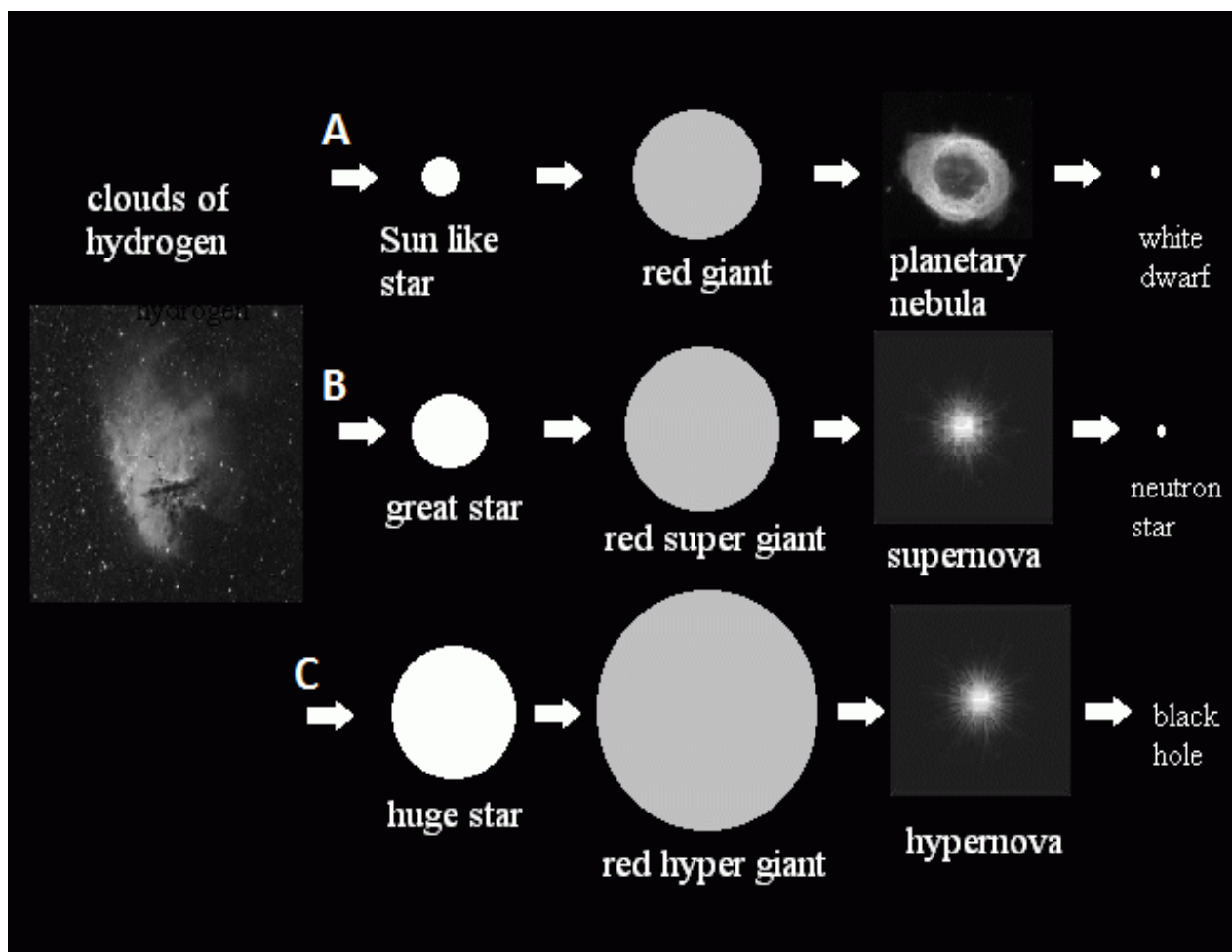
*Neutron stars radiate! As opposed to black holes, they beam light and other forms of electromagnetic radiation.
(Artist's impression, Wikipedia)*

Neutron stars also radiate other parts of the electromagnetic spectrum i.e. simply radio waves. 1967 was the year when this effect was verified by a team with a Prof. Hewish in Cambridge. He monitored 82 MHz (a frequency close to the VHF FM radio band) and his Doctorial candidate, Jocelyn Bell heard for the first time, a typical rhythm of the noise from a neutron star. The apparatus involved 2048 Dipole antennae, arrayed in a complex configuration. They occupied the area of a football field and all antennae fed one highly sensitive receiver.



*The Radio Telescope
in
Effelsberg/Germany,
built in 1972, with a
diameter of 100m, it
was the largest of its
type for some
considerable time. It
was ideally suited for
the detection of
Pulsars (Wiki)*

The received signal from an unknown source was heard three times per second. It was so regular that the scientists thought that this transmission was a message from aliens in outer space. The newspapers assumed that they had detected “little green men“, quickly assigned the letters LGMs. But soon other signals were found, having a different pattern of breaks in their rhythm and located at other spots in the sky. Obviously, these were celestial objects and were given the name *Pulsar*. Later it was recognized that these signals came from neutron stars.



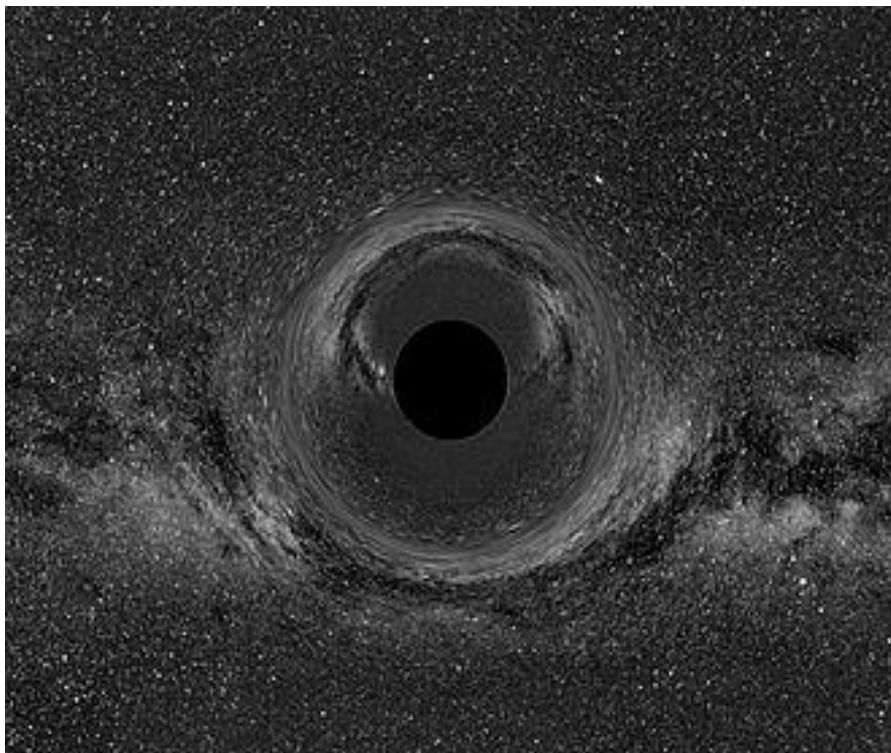
*The evolution of stars, from birth to burn-out
(depicted by the author)*

On the upper (simplified) overview, the life cycle of stars is illustrated. From left to right depicts, clouds of hydrogen forming smaller and larger suns under the influence of gravitational forces.

Smaller stars like our Sun become Red Giants after a lifetime of about 10 billion years. After collapsing, their remnants form White dwarfs garlanded by a ring of smog which forms a planetary nebula, nice and colourful (see path A). Stars greater than ours will become Red Super Giants which end as Supernovae (path B and C) in a big explosion. The remainder will become Neutron stars or even form black holes.

Another possible fate for Red Super Giants – a Black Hole:

When the period of stellar fusion is complete and all hydrogen is converted into helium and other elements, the star will collapse, ending in a big explosion. It is the same procedure which happens when forming a neutron star: the remaining matter will be reflected by its own mantle and a shock wave will return to the core. The direction of radiation will be reversed and a small but dense core of highly compressed matter results. A Supernova will appear in the night sky but with a difference: the reflected matter will not stop but the process of collapse continues. Even when the Schwarzschild radius is reached, the process of mass concentration continues unstoppable. A singularity will appear. Because of the immense pressure and gravity, light is unable escape, imprisoned in a gaol only kilometers in diameter – a new black hole is born.



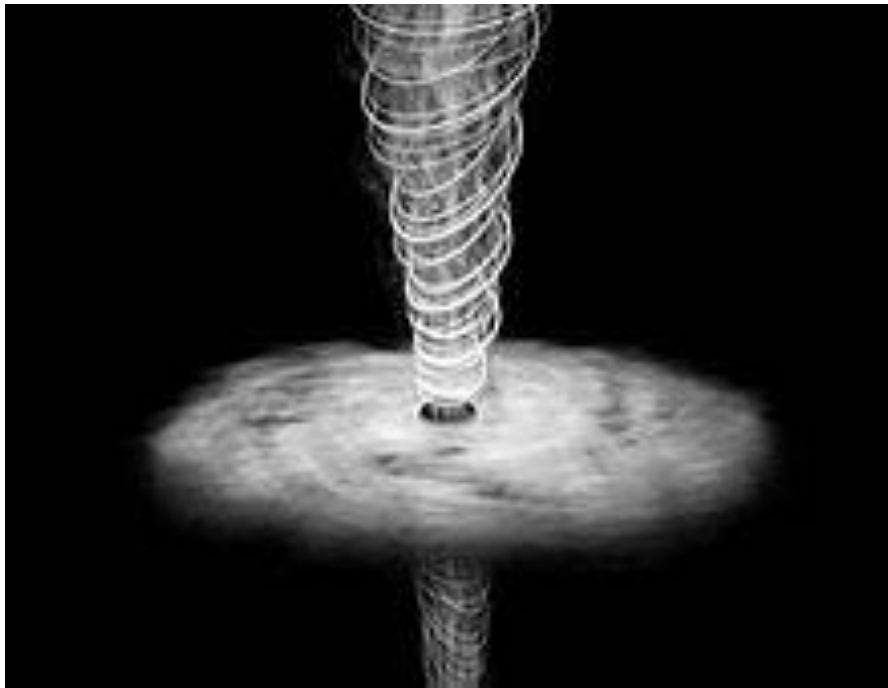
A Black Hole – an artist's impression (Wikipedia)
Because of the gravitational lense effect, the Galaxy in the background seems to be warped and distorted

As we have already seen, the size of a black hole depends upon the spectral class of the Red Giant from which it emerged, mostly class O. Nothing can prevent them from becoming even bigger. Absorbing more and more matter over time, they may be like a vacuum cleaner in space. There are still copious amounts of clouds in space containing the dust of hydrogen which will be attracted when straying too close to the monster (see the picture on the cover). So far, we know from Science that in the centre of every galaxy, a black hole is located. Some galaxies contain black holes with a mass of more than a million or sometimes (in rare cases) billions of stars. Such black holes are called *Supermassive Black Holes*. The transformation of an ordinary black hole to a supermassive black hole is spectacular. This extraordinary physical process came to the attention of researchers in recent years. Galaxies rotate. Hence there will usually be *accretion discs* formed, orbiting their centre. Because of friction of inter-stellar matter, radiation which can be detected on Earth, is generated. Putting it a bit dramatically, it is the death scream of matter, plunging into the Black Hole, emitting all forms of electromagnetic radiations: X-rays and Gamma-rays appearing at the event horizon. But the core of the black hole remains invisible.



*An Accretion disc
encircling a black hole as
it absorbs an orbiting
partner star (Artist's
impression, Wiki)*

Radiation coming from accretion discs of supermassive black holes in the centre of Galaxies, is so bright that it is easily detectable even at distance. Having such extreme brilliance, it can readily be seen on earth. These kinds of interstellar objects also called *Quasar*, standing for “Quasi Stellar Object” or “Looking like a star”. It is the understanding of Physicists today, that quasars are the core of Galaxies consisting of supermassive black holes. Emitting an immensely high level of energy in all parts of the electromagnetic spectrum, they appear very brightly in the Universe. The huge brightness in the centre is so intense that it outshines the rest of the Galaxy. Within a short period of time, more energy is released than was released during the entire previous lifetime of that Galaxy.



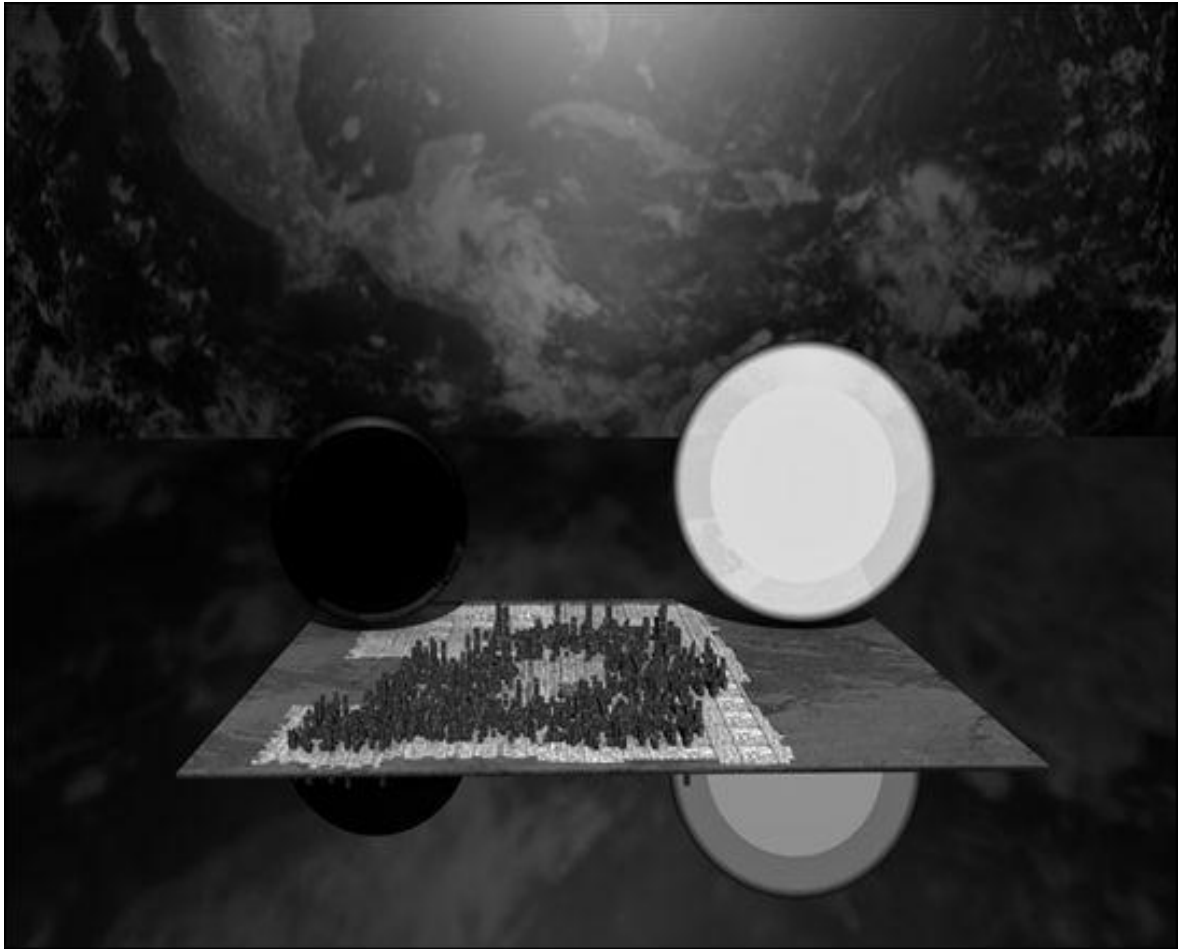
Artist's depiction of a Quasar (Wiki)

That process leading to quasars has similarities to the one creating supernovae but is *not yet fully understood*. The energy level in quasars is much higher compared to the supernovae. It is all related to supermassive black holes.

We can summarise:

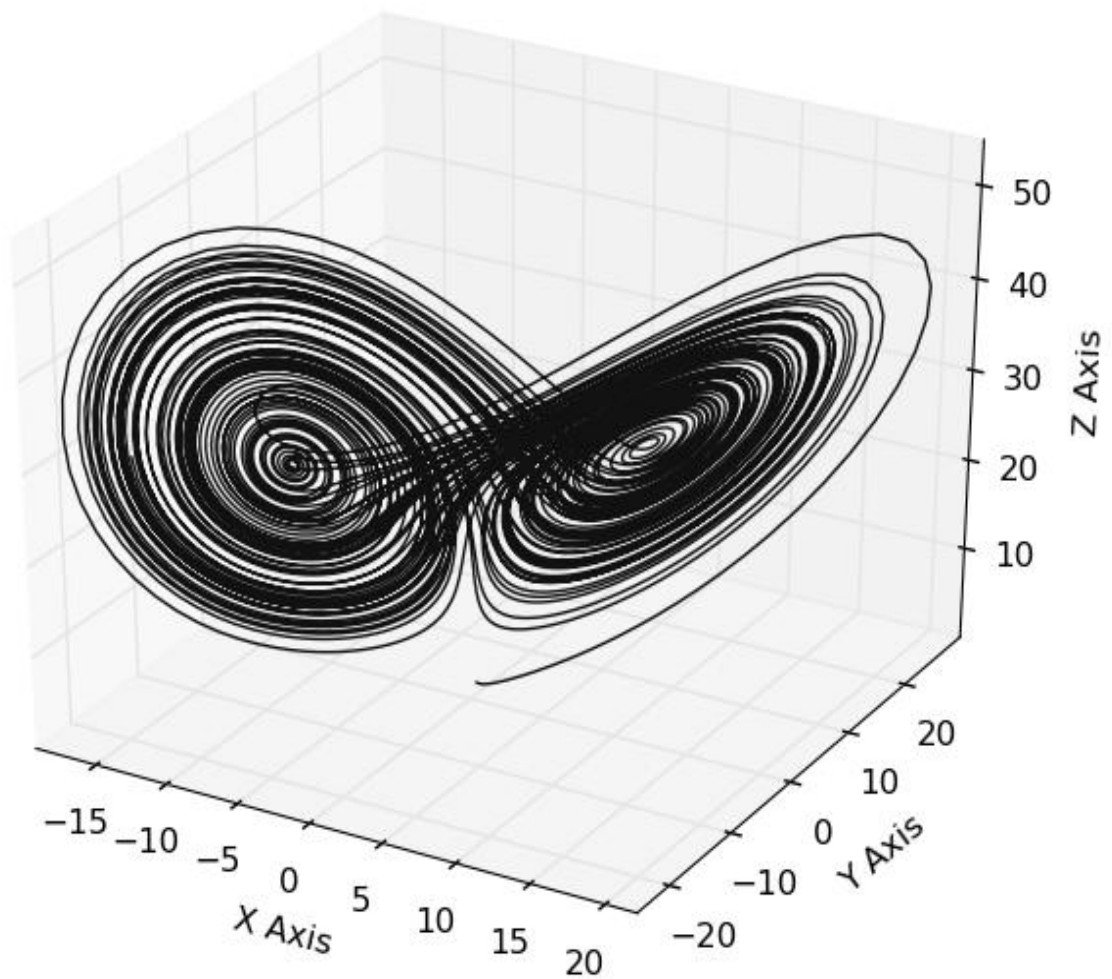
- A Black Hole comes into existence when a big star called Red Giant collapses at the end of its life .
- Chandrasekhar calculated that the size of a Red Giant must at least be three times the size of our Sun in order to form a black hole
- Super Massive stars may explode first before appearing as a Black Hole. This we call a Super Nova
- If the star is smaller than the size of our Sun, then a Planetary Nebula is formed at the end of the sun's life.
- Inside the Planetary Nebula there remains a small dense core called Brown or White Dwarf.
- Probably every Galaxy has its own Black Hole at the centre
- In a few Galaxies there are many Supermassive Black Holes which might explode as Quasars as well.

It is quite interesting to imagine a black hole with a diameter of, let's say 10 km, distant from a neutron star.



A Black Hole beside a Neutron Star, both about 10 km in diameter, over a virtual landscape (Wiki)

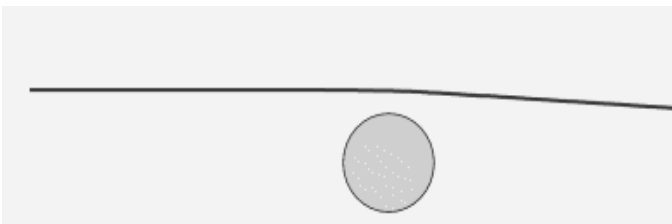
This depicts a black hole with a Neutron Star and how they would appear over a virtual landscape 30 x 30 km in size. Of course this landscape would have been destroyed utterly. Both celestial objects would be attracted to each other with unimaginable force. The one with the greater mass would emerge as the winner, the black hole. By the calculation of Chandrasekhar, it should show that the black hole possesses the greater mass compared with the neutron star.



Calculations with so called “Attractors” are an important mean in the understanding of the forces of Supermassive Black Holes and even Galaxies. The computer graphics show the force field lines between two big masses having great mutual attraction. In this graph, both masses are about the same size. It shows the direction of the exchange of masses. At the end of the process there will be only one great object be left, comprising the combined mass of the two previous objects. This was anticipated.

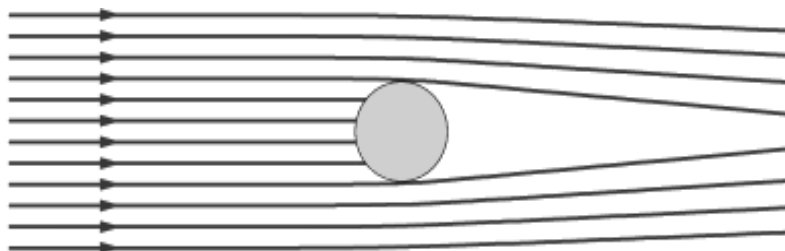
In Golm 2001, scientists of the Max Planck Institute for Gravitational Physics, with the help of a supercomputer could for the very first time, observe a collision of two Black Holes on their screens. The finding of this simulation was that waves of gravitation will be transmitted into space. Until now, such gravitational waves were unconfirmed.

In dealing with black holes, it is important to learn that Einstein had predicted the deflection of light by massive bodies. 1919 this theory was proved by an expedition to Africa conducted by **Arthur Eddington**. He was a British astrophysicist of the early 20th century and took a picture of a star close to the Sun but being eclipsed by the moon. The star's true position was detected exactly at that previously calculated by Einstein. That proved the Sun was acting as a lense for light waves and so deflecting the light.



*Einstein had predicted the deflection
of light by gravitational forces from
massive celestial bodies*

Einstein had stated: Light is deflected by massive bodies just as it is by glass lenses: they will refract the light. If that that happens by gravitational force from massive celestial bodies, they are said to be acting as “gravitational lenses“



*Massive celestial bodies act as gravitational lenses focusing
light*

Some Photos of space objects, taken in the past using the most highly sophisticated telescopes, ever known, were a mystery to astronomers. They show the same celestial object (a galaxy, a supernova within a Galaxy or even a quasar), repeated several times. It soon became obvious that these kinds of pictures reveal the presence of a huge gravitational lens, e.g. a black hole or another Galaxy. The lens was named the Einstein Cross in honour of Albert Einstein, whose Theory of Relativity predicted the phenomenon decades before the first gravitational lens was observed in 1979.

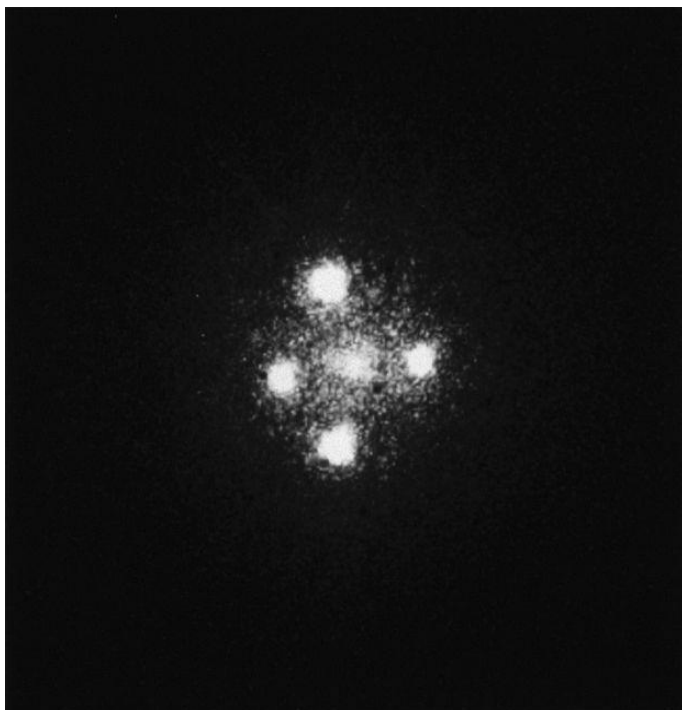


Photo of a gravitational lens, taken on board NASA's Hubble Space Telescope, showing four images of a very distant Quasar, which images have been multiplied by a nearby Galaxy G2237+0305 (By courtesy of NASA&ESA)

The bright object at the centre is a distant galaxy. The four bright objects surrounding it are actually multiple images of a single quasar that lies far beyond the galaxy. A black hole would reveal its presence by the very absence of a bright object at the centre. Sometimes an Einstein-Cross can become a ring depending upon the distance of the observed object from the gravitational lens. All such images are proof of black holes, with further and even *stronger* proof being the image on the frontispiece of this book, the author's very reason to produce it.

Flight to a Black Hole

Imagine it is the year 2113 – a new space ship equipped with mighty ion thrusters, is ready to leave the earth to explore open space. Its destination is a Red Giant called Antares, situated in the star configuration Scorpion. Antares having 17 times the weight of our Sun, in accordance with the calculations of Chandrasekhar - turned into a Supernova with a black hole at the centre. Since it exploded, the former huge red star is able to light up streets on Earth at night. Visibility during daylight, makes Antares a major attraction on Earth.

Our space ship will be powered by a warp drive, a hypothetical, faster than light, propulsion system. The warp drive also will need to be *very* efficient when counteracting the massive forces encountered, close to the black hole .

The crew is to investigate a black hole, formerly Antares, at a distance of 600 light-years from Earth. Reading this book has well prepared the crew for its mission.



Count-Down:
4-3-2-1
LIFT OFF!

Highlights of the Red Giant Antares :

- Approx. 600 Light-years distant.
- Surface temperature about 3,500 Degrees.
- 65,000 times the brightness of our Sun
- 820 times the diameter of our Sun
- Spectral class B
- Colour: deeply red, often confused for Mars

Fortunately the axis of rotation is not directed towards earth so our home planet will remain quite undisturbed by the radiation and flares of the Supernova, the X-ray and Gamma-ray beams of the black hole at the centre. Antares had a companion star, which added to the mass of the binary system, making the situation even worse. Both stars have disappeared and a supermassive black hole has emerged replacing them. What will happen to our crew when travelling to that incredible destination?

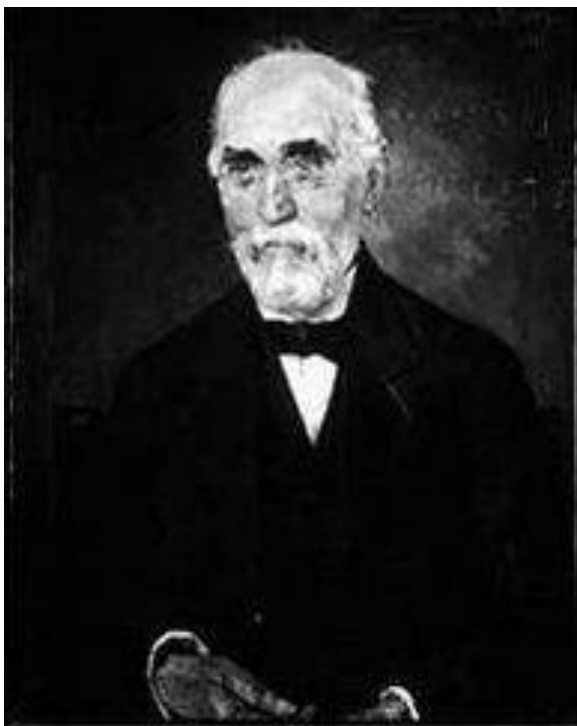


*Antares, is a super Red
Giant, which has a
companion star in orbit.
Photo taken by the Author in
July 2013*

After launching from Earth, the space ship will accelerate progressively. The acceleration is chosen such that the crew feel comfortable, approximating Earth's gravity. After a year's flight time the speed of the spaceship will have achieved approx. the speed of light - according to the laws of Newton ($t = v/b$). By then, the spaceship will be travelling a distance of one light-year per year. At that point some strange effects will appear, as predicted at the end of the 19th century by a physicist named **Hendrik A. Lorentz**.

Lorentz discovered in 1892, that for a fast moving mass (our space ship is one such) a contraction in length will occur in line with the movement. He devised the formula:

$$L = \frac{L_0}{\gamma(v)} = L_0 \sqrt{1 - v^2/c^2}$$



*Hendrik A. Lorentz,
1853-1928, a Dutch
Mathematician and
Physicist, laid the
foundation of
Einstein's Theory of
Relativity (Wiki)*

As early as 1892 Lorentz had described a phenomenon now called the *Lorentz-Contraction*. It relates to any observer of objects travelling at high speed. Such objects experience a contraction of the length, in the direction or line of movement. He came to this astonishing conclusion whilst checking the results of the experiments of Michelson and Morley (see p.24). Later, Einstein reused those findings of Lorentz in his equations describing the Theory of Relativity.

The following chart will make use of Lorentz’s formula in calculating the contraction of any object (here, our ill fated space ship) by the factor γ versus the velocity v towards c , the speed of light. $V=0$ means no movement, $v=0,99$ means a speed of 99% of the speed of light.

V	Contraction γ
0 (Ship dormant)	1 (no contraction)
0.2	1,020
0,4	1,087
0,6	1,25
0,8	1,67
0,9	2,29
0,99	7,09
0,999	22,4

Table of the contraction factor calculated with the help of the Lorentz Formula: Ship speed v versus the contraction γ

In this equation, it is assumed that for the observer of relative movement, the length of the object is measured by subtracting the simultaneously measured distances of both ends of the object. For example: for a moving object with the speed of 90% of the light, its length will become half, when measurement is carried out in the direction of the movement. The width does not concern the observer, remaining constant during the observation. This means, that the appearance of the spaceship (*to the Observer*) is distorted and foreshortened

A spaceship with a speed of 90% of light will be contracted by half in the direction of travel



Einstein said:
“The Lorentz contractions really *do* exist in such a way ... for any non moving observer“

Einstein recognized another phenomenon, closely related to the Lorentz contraction: he noticed a change of time on-board fast moving objects, by the name of time dilation. This Latin phrase means “delay, suspending or respiting” of something and stands for the fact, that time will change within any fast moving object. In Lorentz’s formula on page 79, the length L simply has to be replaced by the time t , the rest remaining unchanged.

In the theory of relativity, time dilation is an actual difference of elapsed time between two events as measured by observers either moving relative to each other or differently situated from gravitational masses. When length L is substituted by the time T, Einstein's formula calculating time dilation becomes:

$$T = \frac{T_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

T stands for the time elapsed on Earth and T_0 for the time in the spaceship. The formula shows that time for a moving object is retarded in relation to another object fixed in space, in same way that its length is shortened. Time dilation is a proven fact. Hence time has to be corrected in the clocks of fast moving satellites of Earth, as in those of GPS navigational systems. Time dilation maintains the order of the Universe and ensures that the velocity of light is constant.

There are only 3 Universal Cosmic constants:

- **The velocity of light c**
- **The gravitational constant (G)**
- **Planck's constant (h)**



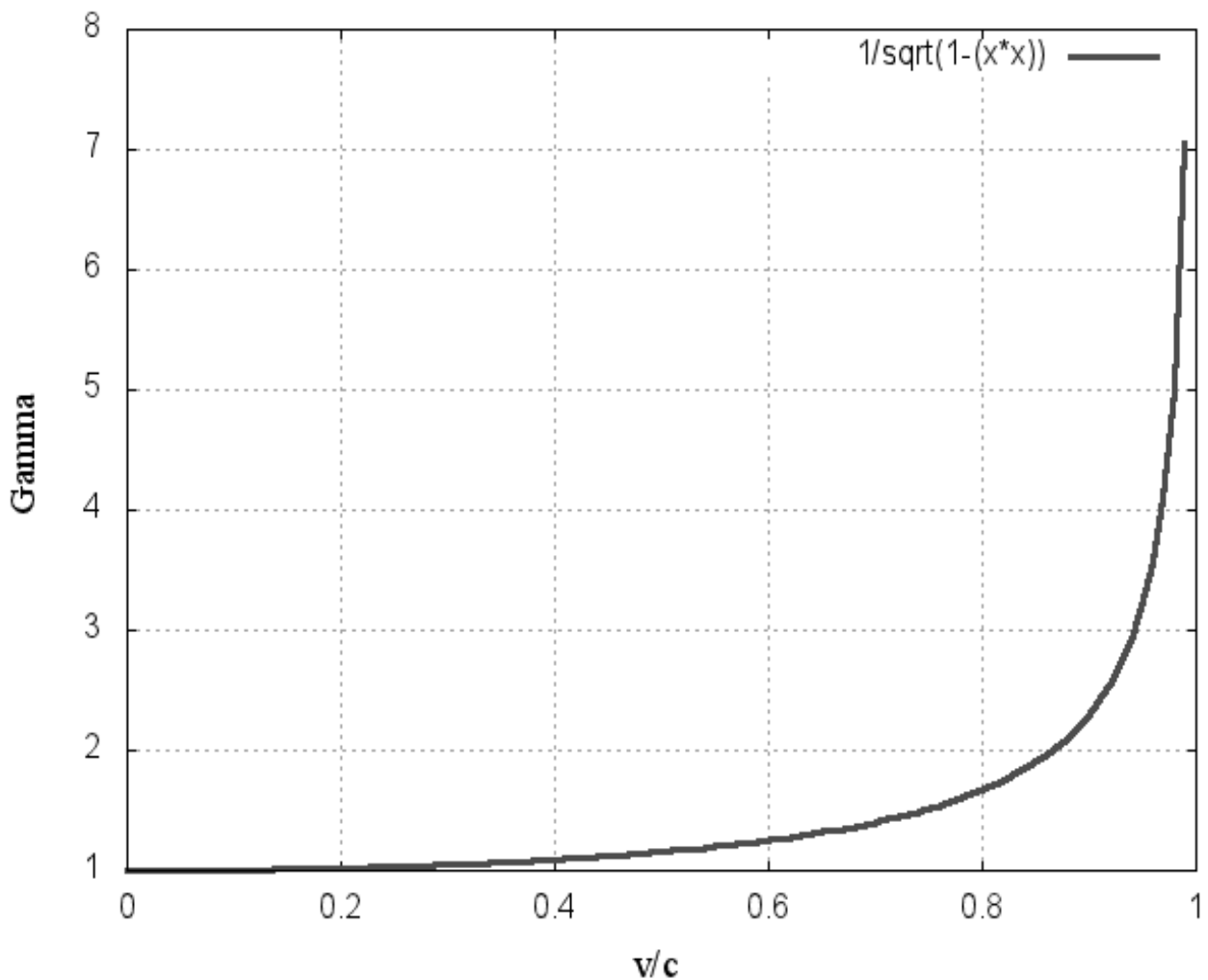
*Mass may
change*

The mass of any moving object will also increase in mass by the same factor γ as it was contracted. The same formula can be re-used. For our space ship moving at 90% of the speed of the light, it means that its mass has almost doubled. Its weight is twice the value it had of starting. In order to increase the acceleration of the ship, more energy is required, *much more*. Again, please note that once again, we used the same formula for calculating mass, length and time dilation for factor γ :

$$\gamma = 1 / \sqrt{1 - v^2 / c^2}$$

It seems therefore that Mass, Time and Space are closely related in some mysterious way. It may well be that they are one and the same manifestation of the very same phenomenon. The formula shows simply that three physical parameters are not permanent nor constant, but the velocity of light *IS*, and quite incapable of any change.

That is an agreement to the contrary, just in the contrary thought 300 years ago during the life time of Newton.



In that formula, if v equals the speed of light, c (So let us set $v=c$) a division by zero will be carried out. Equally, we had, when discussing Newton's formula concerning the attraction of two masses (see page 13), if the distance is set to zero, the result becomes mathematically infinite. In physical terms it means that mass and time will become infinite. All of this makes no sense in the real world. It becomes quite obvious that the equations of Einstein, in the case of fast moving objects, are no longer valid. When an object approaches the speed of the light they can't be used any more.

Einstein and his predecessors Lorentz, Minkowski et al were busy studying the behaviour of space and time among moving inertial systems. Einstein's conclusion was that they were both the same, both were accepted. Einstein's formula is only valid when these moving inertial systems move at a velocity lower than that of light. Because of the equations of Lorentz, Einstein found that space, time and mass are variables and not fixed values, depending on their state relative to each other.

Einstein recognized that the speed of light is invariable but mass, time and space are not!

**His famous statement was:
“God will not play dice“**

Usually we do not notice the relativistic effects on Earth because all movements happen too slowly to measure. Even the high speed of Earth itself, orbiting The Sun at a speed of 30 km per sec is too slow, compared with that of the speed of light at 300.000 km per sec.

But the Global Positioning System (GPS) for instance has to take into account such time dilation for the clocks on board. To achieve high accuracy, various corrections have to be carried out which prove the truth of Einstein's equation of the Theory of Relativity.

With the ever-increasing speed of the space ship, time is steadily retarded for any travellers because of the effects of relativity on board. When years, decades and centuries have passed by on earth, time on board the space ship has changed by only weeks and months. In the case of the Crew's deciding for any reason (perhaps feeling home-sick or because of any technical malfunction) to turn round and head home, they would find that their home planet would have aged far more than they had. Watches on board may show travel time of some months, while earthbound clocks would indicate that some hundreds of years had passed. It is quite likely that nobody on Earth would know a thing about this space ship which had set out for Antares so long ago. The brave crew could have been quite forgotten by now. Towns may have been destroyed and even the language will have altered.



Home planet Earth will have aged and may have changed completely beyond recognition when space travellers return from a long, high speed journey (Wiki)

All relatives would certainly be dead and it might well happen that the world has changed completely. Obviously, the travellers would have arrived at home well into the future. How far into the future their voyage might be, would depend upon their speed of travel. In accordance with the formula of the special theory of relativity, it is quite possible to undertake journeys into future. However, journeys to the past are definitely ruled out.

If nature *did* allow journeys back into the past, a so-called time paradox would appear. The Time Travellers could interfere with events which had happened far in the past and therefore alter the situation at the present time. For instance, a man could arrive and interact with a certain event before he had been born. Time-paradoxes could arise if reverse time-travel were allowed by the Universal law. To avoid such paradoxical situations, backward time-travel seems to be excluded by nature. The latest studies confirm that theory.

However, that means, that our Time Travellers are now marooned in the future. There is no way back to the past. Utter Disaster. Fully aware of that, our crew decides to press on with their “Voyage Into The Unknown“.



*Time- Paradoxes!
Flights into the future
are possible but
backward time-travel is
not*

They continue their ill-fated flight towards the black hole. The crew meanwhile, has detected the black hole that has been created inside the supernova, formerly Antares and they are fast approaching the event horizon.

The instruments on board tell the crew of the presence of a bright accretion disc, emitting X-ray and Gamma-ray and other forms of electromagnetic radiation, around the black hole. Accretion means the conversion of gravity into pure radiation power. The crew trusts its shields. Moreover, they have read some bad Science Fiction literature, believing in travelling to distant galaxies with the help of so-called Worm Holes, interconnecting some kind of black holes. Just wait until they try!

What will happen? The space travellers, attracted by the black hole, have already reached the “Point of No Return.”

There is no way back!

The space ship has begun to orbit the black hole irretrievably, together with all kinds of interstellar matter, attracted by the same circumstances. Arriving in a helical trajectory, the space ship will experience lateral forces when approaching the black hole. These lateral forces compel all matter into orbit, in the same huge and flat disc plane at ever increasing speed and in accordance with the formulae of Einstein and Lorentz. The space ship will gain in mass, weight and velocity. Time on board will be further delayed until it will stop completely. The travellers will notice none of that because they are part of the same inertial system.

Observers on Earth would have noticed that the speed of the space ship had diminished, eventually coming to a standstill. It would have stuck at the event horizon for long time, deadlocked.

Before becoming invisible from Earth, the space ship would have seemed to be fixed, glued at the event horizon, fixed in front of the black hole. These illusions gave the name to black holes before 1967. They were previously known as “Frozen Stars“.



*The space ship,
dead-locked at
the event
horizon of a
black hole
(Wiki)*

Fast moving objects, approaching a Frozen Star, will under-go strange effects. Observed from Earth, they gain mass. Time is retarded until deadlock and because of the Red Shift of light, they become invisible as they disappear into oblivion.

Now the space ship has crossed the event horizon and has entered a zone within which the laws of the Theory of Relativity are no longer valid. From this very moment on, the space ship will become invisible to earth.

Ship and crew inside the Black Hole will experience that which all interstellar matter suffers under such extreme conditions including Red Shift and Time Shift or dilation. This will be described on subsequent pages.



*The Black Hole:
because of the immense
gravity, a disk of
accretion has formed,
emitting deadly
radiation (Artist's
drawing, Wiki)*

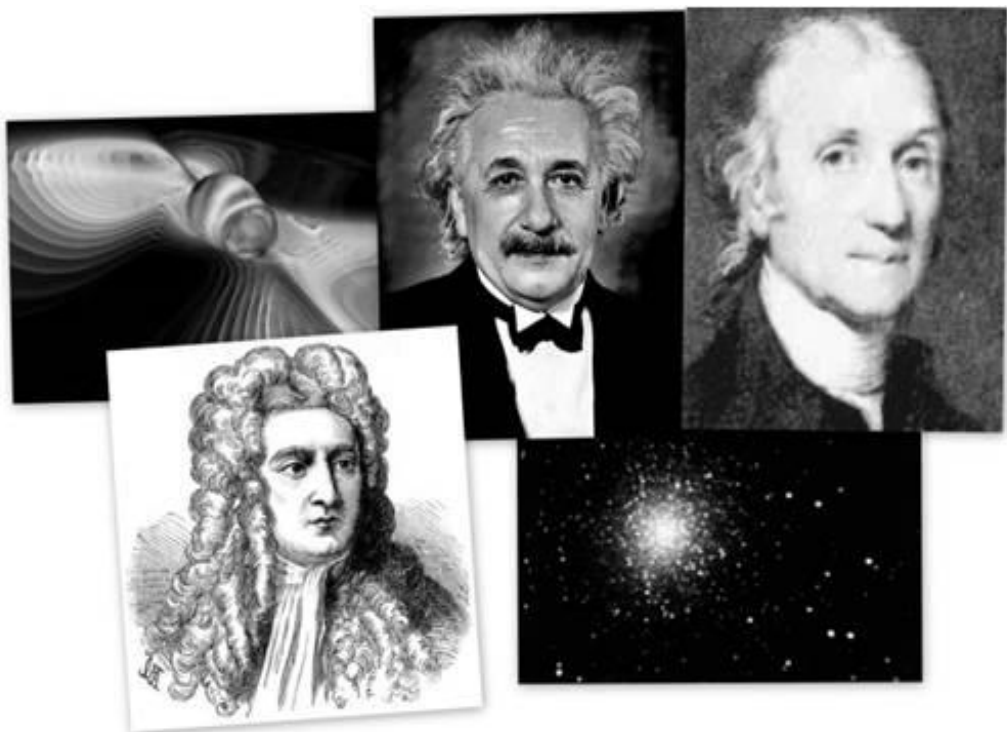
The question now arises as to whether the space ship has actually reached the Black Hole or not. The answer to that question is a definite yes, but not in *our* time!

Objects approaching a Black Hole experiences a Red-Shift and a time-dilation simultaneously!

What would happen to a space ship and its crew, irrevocably crossing the event horizon of a Black Hole? We shall see in the next pages.

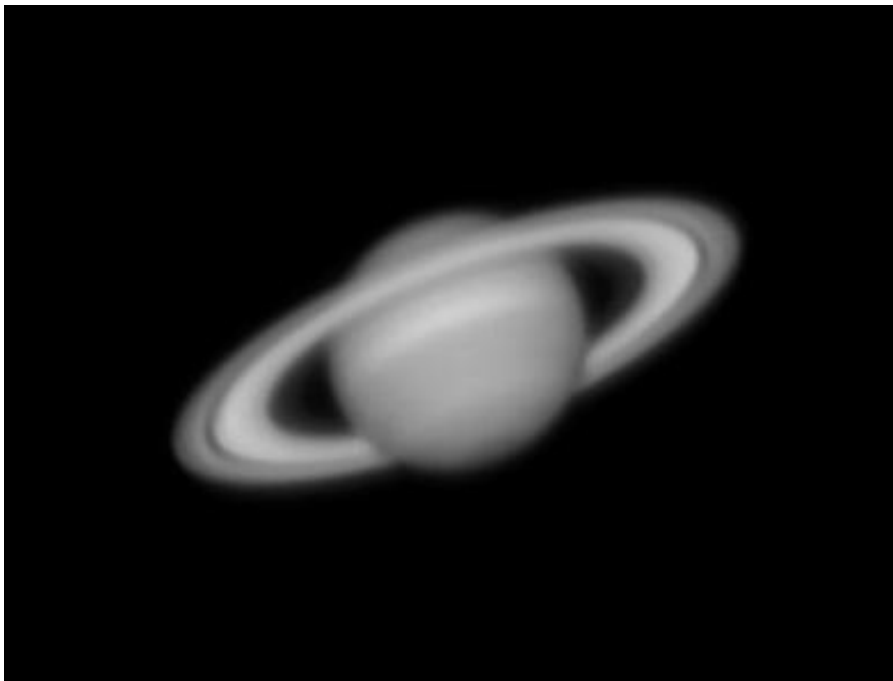
Here is the bad news first: the crew would be killed by the immensely high level of all kinds of radiation, from the the *accretion forces* when crossing the event horizon. High temperatures, hard X-ray and Gamma-rays, all are deadly. Hell could not be worse. Furthermore, close to the black hole another, huge force, *Tidal force* appears. The gravitational attraction of any massive celestial object can become immense. Close to the black hole this force causes the slim prow of the space ship to undergo much greater attraction than the stern. Fore and aft will be pulled apart like chewing gum. This perturbing force has yet another nasty consequence.

Force field lines passing through the centre of the black hole, the singularity, are not in parallel. This leads additionally to a lateral component of the gravitational forces, crushing the tortured space ship. Stretched like spaghetti and squeezed, the space ship will collapse, disintegrate and break up. From this point, there is only one course for the shattered remains of the space ship: towards the singularity in the very centre of the black hole.



The expression “tidal force“ originates from the influence which the Moon has on the Earth’s seas. This force triggers the twelve hourly ebb and flow of tides, at half the speed of the Earth’s rotation.

In celestial mechanics, the expression tidal force can refer to a situation in which a body or material is mainly under the gravitational influence of a second body. That usually happens when two celestial bodies venture too close to each other.



*Saturn – picture taken by amateur
astronomers of the VSW Munich*

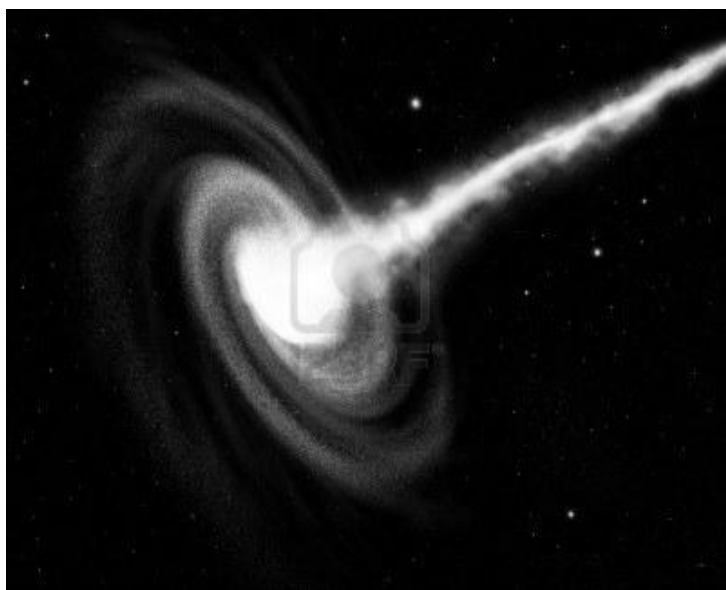
Saturn – the 6th planet in our Sun system – is supposed to have had a former moon, broken into pieces by the influence of Tidal forces when straying too close to Saturn. The remaining debris of its moon, forms a spectacular ring which can easily be seen through binoculars at a clear night sky.

What happens to the rest of the material ?

Beyond the Schwarzschild-radius, no research can be carried out. It is beyond the range of scientists on Earth. It is also supposed that all equations of the theory of relativity, cease to be valid in that area of extremes. Time will terminate at the final point, the singularity. This point has infinite density and zero size. But one thing is likely :

The components of all the atoms of any matter feeding the black hole (this means ship and crew) are probably still in existence. These components are the electrons, protons and neutrons in a form we call degraded matter, in same form as the inside of a neutron star. We can only assume that, not knowing for absolute certainty.

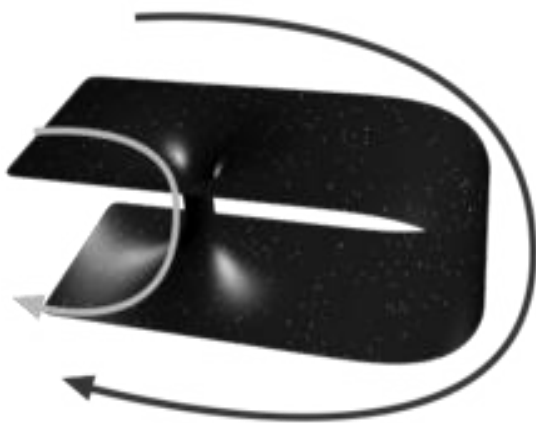
Speculations on the internal conditions of a black hole have long been under discussion. We will continue to focus upon them.



*Matter will degrade
inside a Black Hole,
acquiring
characteristics close
to those of Neutron
Stars.
(Artist's impression,
Wiki)*

The laws of Physics are usually symmetrical. This means that if something is consumed by a black hole, something *must* be lost, to keep space in balance. This would also satisfy the Laws of Thermodynamics. If so, that would mean that black holes are able to grow, diminish and eventually disappear.

Is it feasible that something could fall into a black hole, and emerge elsewhere in space? Such a place is called a “*White Hole*“, predicted and favoured by science fiction authors, who speak of “wormholes“ allowing fast and easy travel throughout space. Even Einstein made calculations about such wormholes in space. They are called “Einstein-Rosen bridges“. Finding them would be an ideal method for providing space travel.



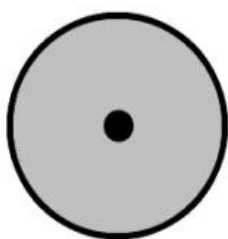
*Perhaps White Holes
do exist, allowing
swifter travel on space
journeys?*

Not only science fiction authors but even some physicists speak of space travel, utilising White Holes for remote destinations. They have predicted the existence of some small and young new universes. If such a parallel universe were to dock with the space-time of our Universe, a new black hole would appear within our Universe. If a space ship could actually survive, indeed a new form of space travel would have been found. However so far, nothing has suggested to scientists any indication of the existence of White Holes.

Inside a Black Hole

It is impossible to look into a black hole. Hence it becomes necessary to employ mathematics for that purpose. An *Event Horizon* has no actual hard surface as in the case of planets. It is a theoretical border defined by mathematics. Beyond that border, no radiation of any type can leave the Hole. We do however, want to know what happens on the far side of the event horizon as the very title of this book might suggest. Probably matter beyond that horizon is aggregated into a small core as we know it to be in neutron stars. Yet a neutron star has no centre called a singularity, whereas a black hole is supposed to have such. Because of the extreme density in that singularity, the formulae of Lorentz and Einstein will very likely no longer apply. Mathematics shows that space becomes time and time becomes space.

EVENT HORIZON

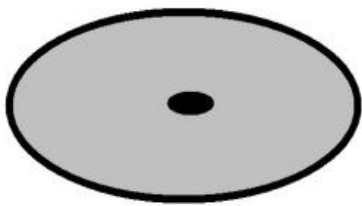


*Unlikely:
A static Black Hole having
a point mass called
singularity at its centre*

Since Karl Schwarzschild, the centre of the black hole has acquired the expression *Singularity*. He calculated that a non-rotating hole contained all of its mass in that centre. (See the chapter “The Previous History”).

Fifty years later it became obvious that every Black Hole possessed some spin. **Roy Patrick Kerr** demonstrated mathematically, that a black hole is a rotating space-time having a *Ring singularity* in its centre and the core in the form of an oval.

Event horizon



Very likely: a rotating black hole with a Singularity in the form of an ellipse containing mass, angular momentum and perhaps electrical charge

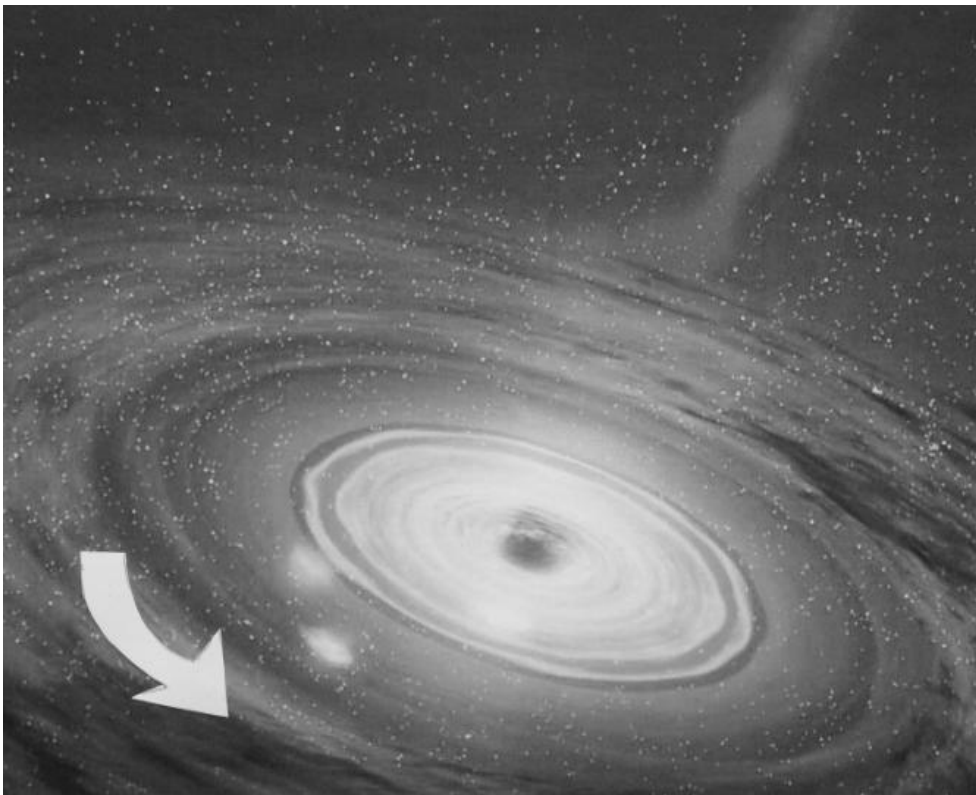
Roy Kerr: born 1934
in New-Zealand,
Mathematician,
contemplated rotating
black holes as early as
1963. He was
awarded The Albert-
Einstein-Medal in
2013 (Wiki)



Kerr's vision of a fast rotating black hole, was that it possesses mass, angular momentum (spin) and perhaps electrical charge, the last not proven. This model found favour until modern times. There are stunning similarities in these characteristics to fundamental particles. Equally, atoms have qualities like mass, angular momentum and electrical charge, with nothing else.

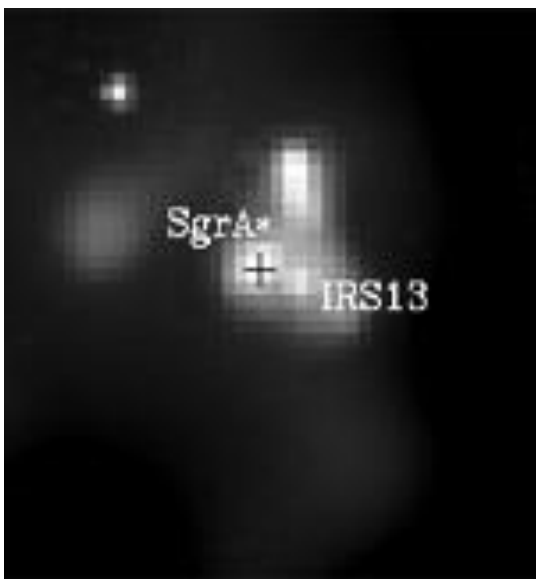
The result of Kerr's calculations showed that a rotating black hole would impart rotation to anything approaching the event horizon. This means that matter, light and magnetic fields, are forced to adopt the spin, the direction of the rotation and the same angular speed of the black hole itself, a behaviour known as *frame dragging*, meaning the taking along of any framework to another frame of reference. Kerr arrived at the conclusion that a motionless observer, beside an event horizon is not possible.

The Frame Drag will cause magnetic fields to become twisted and amplified significantly. So-called Alfvén waves will be created along the axes of rotation, becoming so immensely strong that at both, poles, matter and all sorts of electromagnetic waves are emitted. This idea is confirmed by calculations in a special branch of mathematics, the so-called Magnetohydrodynamics.



*Frame Dragging, creating jets at the poles of a Black Hole.
An artist impression (By courtesy of ESO)*

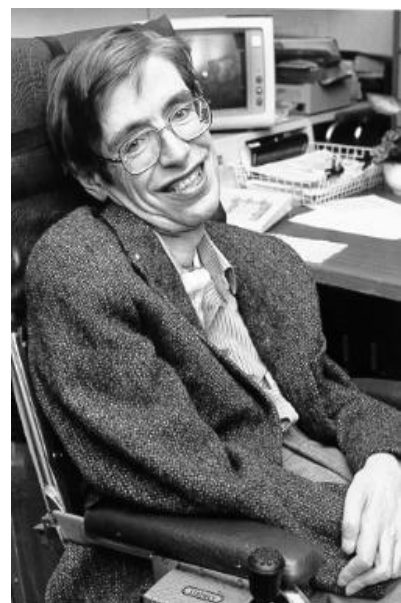
The result of all such effects is that matter which is heated in close proximity to the “Kerr Hole“ will be ejected from the poles at high speed. Presumably, this will be a kind of high temperature plasma. This polar jet, a phenomenon in astrophysics, created by the mechanism of Magneto-hydrodynamics, may reach millions of light-years into space. **Polar jets** are streams of matter emitted along the axis of rotation of a fast rotating star. They seem to play an great role in the cosmic cycle of life. Supernovae caused by collapsing Red Giants, will distribute vast amounts of matter into space. This matter will be re-distributed over great distances when approaching a spinning black hole. Remember, that matter from any supernovae will contain many elements (e.g. carbon, iron, etc etc), the basic modules of new sun systems. Black holes seem to be the essence, not simply the destruction of destroying stars but also the very creation of new ones. This includes planets and complete star systems like ours. The significance of black holes to life seems to be immense.



In the centre of the Milky Way is Sagittarius A . A black hole having the mass of 4 million times our Sun, is situated at the centre (see also cover illustration, image by courtesy of ESO)*

A black hole is a celestial object with a sudden appearance. It is expected to grow permanently. Will a black hole exist forever? Will it grow perpetually by absorption of any matter randomly approaching too closely? Will it continue “in perpetuum?” For many years, such questions occupied the brilliant mind of **Stephen Hawking**, the famous British theoretical physicist, cosmologist, author & Professor at the University of Cambridge. Hawking suffers lateral sclerosis (ALS), also referred to in the USA as Lou Gehrig’s. Doctors predicted a short life for him. To overcome his difficulty with speech, he needs the assistance of a computer and speech synthesiser. To this day, the famous Professor Hawking is alive and working on Black Holes. Before 2004 Hawking supported Wheeler’s “no-hairs theorem” (see page 37). He had a bet with a colleague, **John Preskill**, who contradicted the theorem. Subsequent calculations carried out by Hawking, had shown that black holes might very well diminish and ultimately disappear by the emission of small amounts of thermal radiation. In 2004, at the Dublin “International Conference on General Relativity and Gravitation” he declared his bet to be lost and conceded that a black hole is not entirely black.

Stephen Hawking, born 1942 in Oxford, made enormous contributions to Astrophysics, focusing on Black Holes (Wiki)



Black holes do have hairs - a metaphor for all kinds of radiation and what Hawking called “information”.

The wager was, showing the British sense of humour, an encyclopedia containing much information on what would survive when succumbing to a black hole. Hawking, in parodying Einstein said: “God will play dice but sometimes the dice cannot be seen!”



Hawking lost his bet: the wager was an encyclopedia

What bothers Hawking about black holes is that they oppose two earlier fundamental laws; the thermodynamic equilibrium and human common sense, both of which say that nothing exists forever. Physics clearly states that in any isolated system (The Universe) the energy in total will remain constant, in accordance with the laws of thermodynamics. Matter would eventually disappear from the Universe if there were no mechanism to allow some to escape from the black hole. Hawking established that a certain amount of radiation can exit from black holes. This kind of radiation was later given his name: Hawking radiation. If Hawking's theory of black hole radiation is correct, then black holes can be expected to shrink and evaporate over time because of the leakage of mass via the emission of photons and other particles.

As early as 1970, Hawking was fascinated with Black Holes, created since the birth of The Universe in the Big Bang. His calculations also resulted in tiny Black Holes, the so called primordial Black Holes. Together with other kinds of Black Holes, identified today, the entire family was assembled - in ascending order of size:

- Primordial Black Holes
- Micro Black Holes
- Black Holes of stellar mass
- Black Holes of enormous mass
- Supermassive Black Holes

In September 2010, a signal that is closely related to Black Hole Hawking radiation was claimed to have been observed in an experiment. The results however remain unverified and debatable.

One of the most important contributions of Hawking was: “*The Black Hole Information Loss Problem*“. Information here, means matter, energy and the laws describing them. Hawking Radiation reduces the mass and the energy of the black hole and consequently it may lose more mass than gained through accretion. As a consequence it will shrink until its mass reaches zero, whereupon it will disappear. This is the clear outcome of Hawking Radiation. The question is how long does it take until it disappears? If the time span is very great – and it does appear that the black hole in the centre of our Milky Way has existed for a long time period – then Hawking Radiation has no effect on the destiny of The Universe.

As it has been determined that a black hole is able to shrink by permanently losing energy through Hawking Radiation, it will, as a consequence be gone after a certain period of time. This period Δt will be calculated through the Hawking equation by:

$$\Delta t = \frac{M^3}{3\Lambda_t},$$

This equation shows how the life-time of a black hole quite depends upon its mass M . One can say “the greater the mass the longer will be the life time“. Conversely, the life of smaller black holes will shorter. The formula will be valid in the case of a black hole which has no chance to add further matter. This could possibly be due to an absence of matter in close proximity. Hawking also tried to calculate temperatures inside a black hole. Surprisingly, temperatures T are inversely proportional to the size of a hole:

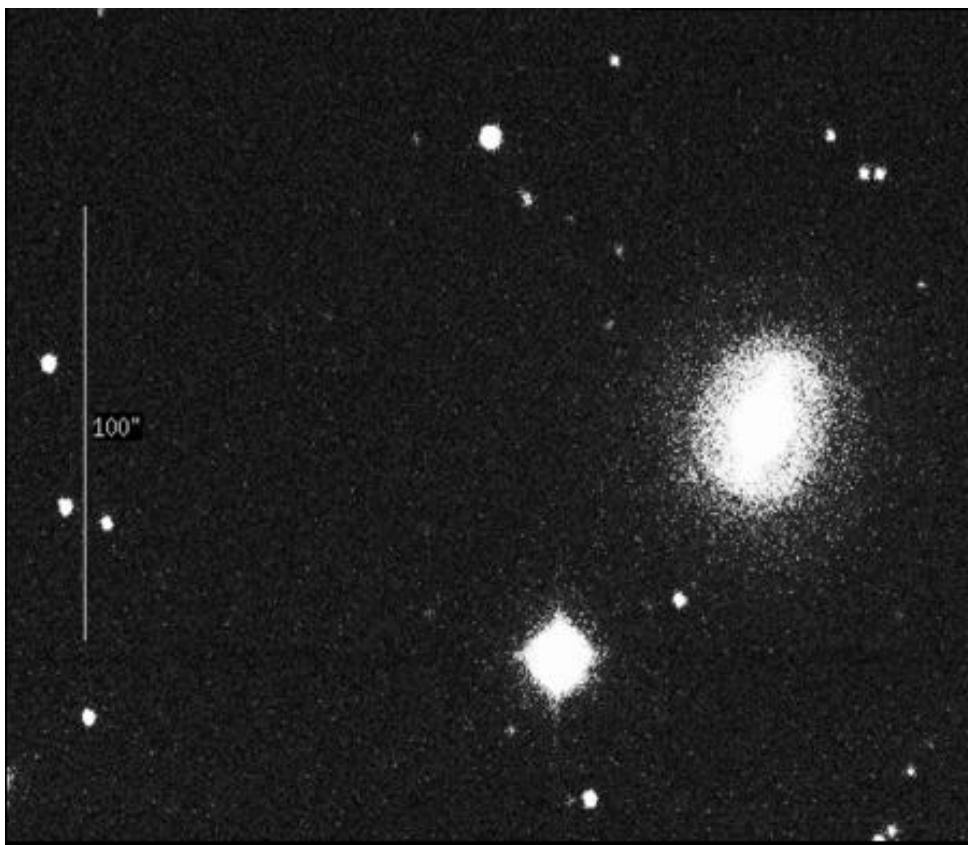
$$T = \frac{\hbar c^3}{8\pi k_B G M}$$

The numerator contains the so-called *Planck's quantum* of action \hbar and as usual the speed of light c . The Denominator contains the constant of Boltzmann k the gravitational constant G as well as the mass of the black hole M . Doing the calculation gives a surprising result: the temperature of a black hole drops as its mass increases. Big black holes have inside temperatures similar to those in a living room.

In June 2013 the headline of a press agency (DPA) in a German newspaper was:

“Black Holes Raise Dust“:

Usually, dust close to a big black hole like the galaxy NGC3783, displays a temperature from 700 to 1000 degrees C. The “Very Large Telescope“ of ESO has measured the core as ‘having a temperature not unlike any living room.’



*This image, taken by the Mexican University UNAM shows the bright Halo around the Black Hole NGC3783
(By courtesy of UNAM)*

This headline impressively confirmed Hawking’s formula. With the use of modern technology, it can now be measured and confirmed what Hawking et al. had supposed, many years earlier.



*Joseph Polchinski, born
1954, American physicist,
involved in studying String
Theory (Wiki)*

2012 **Joe Polchinski**, working at the University of California set off a controversial debate. His argument: Everywhere in the Universe, new pairs of particles and antiparticles come into existence, interacting with each other. If that happens close to the event horizon, it might be that one part of the pair were captured by the black hole but not so the partner. In that case the remaining particle would appear to us in the form of visible radiation. The rest would be captured by the black hole in the form of negative energy, diminishing it and eventually causing it to disappear. It would evaporate. Hawking's work was confirmed.

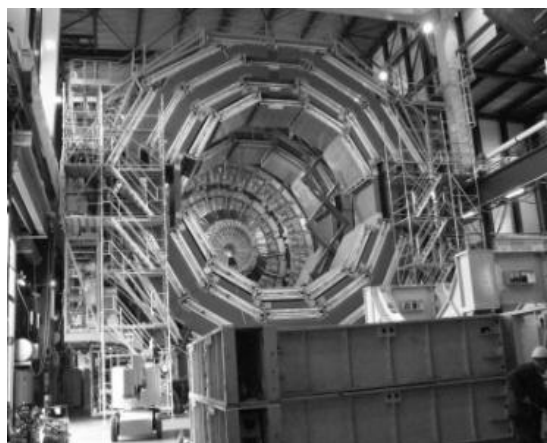
Polchinski concluded that the interlacing of particles would be stopped under the release of great amounts of energy in the form of X-rays and Gamma-rays. The event horizon would destroy everything close to it, in a ring of fire. If Polchinski were right, space travel by the use of black holes and worm holes, into parallel universe would be impossible. (see the previous chapter "Flight to a Black Hole")

We can summarise:

- A Black Hole can actually shrink due to the emission of Hawking Radiation
- Small Black Holes will exist for a short period of time: big Black Holes accordingly longer.
- Black Holes are cooler on the inside, the greater is their mass, the bigger they are.
- Black Holes can be detected only indirectly, with the help of, amongst other things, Einstein Crosses
- Beyond the event horizon no observation is possible. Only with the help of Mathematics, will further investigation be feasible

In the case of a black hole radiating or leaking Hawking radiation, its energy will be reduced. In accordance with Einstein's formula $E=mc^2$, the hole will lose mass and diminish. Just how small can black holes become? Is it possible that tiny Holes exist and could they become entirely extinct through out the Universe? These kinds of questions are discussed in the community of astrophysicists. Since 2008 at the world largest particle accelerator, the *Large Hadron Collider* (LHC) at CERN (Centre Européen pour la Recherche Nucléaire) in Geneva, high speed protons have been emitted. Black holes are expected to be produced if these particles do collide with each other.

*Picture of the Large
Hadron
Collider in Geneva
(By courtesy of CERN)*



Criticism and concern arose from people, anxious about the possibility that tiny Black Holes which could grow rapidly, might be created, with the obvious danger that these could present. In 2012 it led to a lawsuit at a court in Münster/Germany trying to bring these experiments to an end. The fear was that these 'man made' Black Holes could lead to an apocalypse not to mention the end of the world. It was argued that a Black Hole if created, could grow very rapidly absorbing all matter inside the collider, wolfing the collider itself and later on Geneva and the rest of the entire world. Doomsday might have arrived. Understandably, this needed to be viewed with concern.



*„Four
Horseman of
the
Apocalypse“ -
painted by
Albrecht Dürer
1497-1498 (The
Revelation of St
John -
Wikipedia)*

The court rejected the objection, giving its reasons for refusal: the majority of the scientists believed that CERN's trials at the LHC in Geneva would not endanger the world. Indeed, the physicists themselves had earlier predicted the creation of small black holes in experiments carried out at the LHC. Because of the low energy levels which were to be applied, it should result in very small black holes about the size of an atom. There would be no danger because any micro Black Holes would degrade quickly, collapse and simply disappear. Anxieties were assuaged.



The huge accelerator at CERN in the form of a ring and is situated underground, having a length of 27 km. Close to the airport (By courtesy of CERN)

The micro Black Hole was not (yet) discovered at CERN, operation being at too low energy level, about 4 TeV – the rig was not yet fired up to full power level. But another particle, on a list of the most wanted: the Higgs-particle was found. In July 2012 CERN claimed that a new, elementary particle had been detected, already theorised in 1964 by a British scientist. This particle having no charge and zero spin, was one of the most sought-after particles in modern physics. It is also called 'The God Particle' because of the ability to give rise to the masses of all the elementary particles. Mass means gravity. Revealing the secrets of gravitation is revealing secrets of Black Holes. Scientists at CERN were encouraged by obtaining results so soon despite functioning at such low energy levels. When the facility is eventually fired up at the full power of 7 TeV, new discoveries are anticipated.

Just how Small can Black Holes be?

Chandrasekhars calculations had shown that the minimum mass of a stellar black hole has to be about triple that of our Sun. How do the physicists expect to get micro small Holes with the help of the LHC at CERN? Do they even exist ? Schwarzschild did not regard any physical limitation for the size of black holes (see his formula on page 28).

Indeed, due to Hawking’s work, there is no lower limit for the minimum size of a black hole. Micro black holes are not excluded by the theory but are obviously very rare in space. Perhaps they might be formed if a certain level of energy were applied at the LHC. Yet if that happened, they would surely have too short a life span to interact with other, surrounding matter. It is quite interesting to investigate what diameters black holes might have. The chart shows the proportional dependencies between the Schwarzschild-radius versus the initial mass:

Initial mass	Diameter of the Black Hole
Micro-Hole	diameter of an atom
Earth	9 mm
Sun	1,5 km
Red Giant	30 km
Milky Way	1000000 km

The Smallest and the Biggest

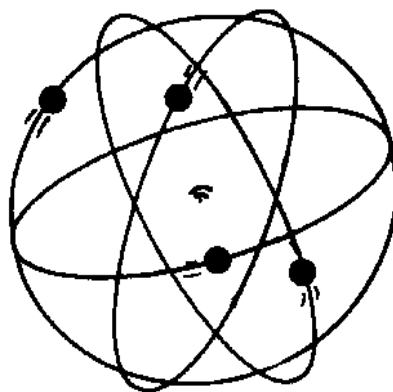
Black holes of stellar mass are rather small objects in The Universe. They consist of – as we have seen in previous pages – the remnants of collapsed red giants which in their part are made of tiny elementary particles. As a consequence of that, the world of the *tiny* must have an enormous significance for the world of the *Biggest*, the Universe. Everything, black holes included, is composed of atoms, or as today's physicists say - of baryon matter.

The stunning similarities between the inner structure of black holes and elementary particles brought some physicists to the believe that they must basically be the same. This will be particularly true in the case of the micro holes which CERN strives to fabricate in Geneva with its LHC.

The elementary particles – this means electrons, protons and neutrons - possesses charge, mass and angular momentum, just as do black holes. The core of the atom is orbited by clouds of electrons, similarly the accretion ring, surrounding a black hole.

All this is reason enough to take a closer look into the atomic construction inside the world of the smallest. Here the author gives a short overview of the former, standard model of particles, the Bohr atom, and the later standard model which is now in use. We begin with the classical Bohr model.

The Bohr Model of Atomic Physics depicts the atom as a small, positively charged nucleus surrounded by electrons having a negative charge, maintaining the balance



The Bohr model, introduced 1913 by Niels Bohr and later revised by Rutherford, is a relatively primitive model of the hydrogen atom (see also page 42) and considered a planetary-model atom. Based upon that model, all of the 92 naturally occurring elements have a core of heavy particles with some electrons in the orbit. The core, consisting of protons and neutrons, provides almost the entire mass. Heavier atoms have more protons in the nucleus, and more electrons to cancel the charge. Neutrons in the nucleus (having no charge) are needed to retain the protons (having same charge) within the nucleus. They play the role of “glue“. The entire atom is in balance and free of charge, if seen from a distance. It soon became obvious that most of an atom would be empty space. Earlier voices had claimed that eventually, nature could significantly shrink the atoms within neutron stars or even black holes, under the influence of gravitational forces. Subsequently outdated, the Bohr model became obsolete but has regained merit because it can explain most but not all effects observed by physicists. Today’s model of the atom is much more complex .

The modern Standard Model of particles:

Since the late 20th century, the Standard Model of particles has replaced the model of the Bohr atom. It is a theory concerning the electromagnetic and nuclear forces of sub-atomic particles and is characterised by implementing additional particles like Quarks. Unfortunately, it is not a complete theory of fundamental interactions because it makes some simplified assumptions. For that reason, this model is sometimes regarded as a “theory of almost everything“.

Quarks & Hadrons:

Both, the Quarks and the Hadrons, have replaced the former protons, neutrons and electrons. There are six types of quarks, known as up, down, strange, charm, bottom and top. Up and down quarks are stable and the most common in the Universe, whereas the others can only be produced in high energy collisions. Quarks belong to the family of Hadrons.

Fermions:

There are 12 elementary particles having spin, known as Fermions and classified by the charges they carry. There are six quarks and six leptons forming fermions. Lepton is the name of a group containing the electron, neutrino, muon and tau particles. Fermions carry colour, charge and the strong force of interaction.

Bosons:

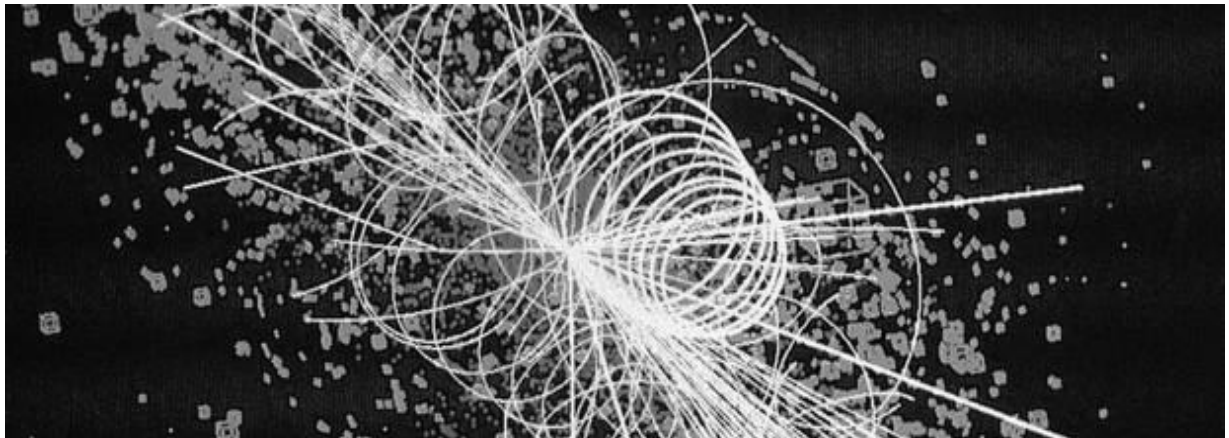
These are defined as force carriers that mediate the strong, weak and electromagnetic fundamental interactions of particles. This interaction happens by exchanging other particles, known as force mediating particles.

Higgs boson:

The Higgs boson confers mass to hadrons and quarks. It plays a unique role in the Standard Model, by explaining why other elementary particles are massive. Its counterpart is a hypothetical particle called a ‘graviton’ which has never been detected. It might be that the Higgs particles and the gravitons are one and the same.

The four fundamental forces in the Universe:

Fundamental interactions or interactive forces are recognized as gravitational, electromagnetic, strong nuclear and weak nuclear. The cohesion of quarks within the core of atoms is achieved by the strong nuclear force and particles with the name gluons acting literally, as a glue amongst them. The atom itself is held together by electromagnetic force. The weak nuclear force induces radioactivity and other electromagnetic radiation.

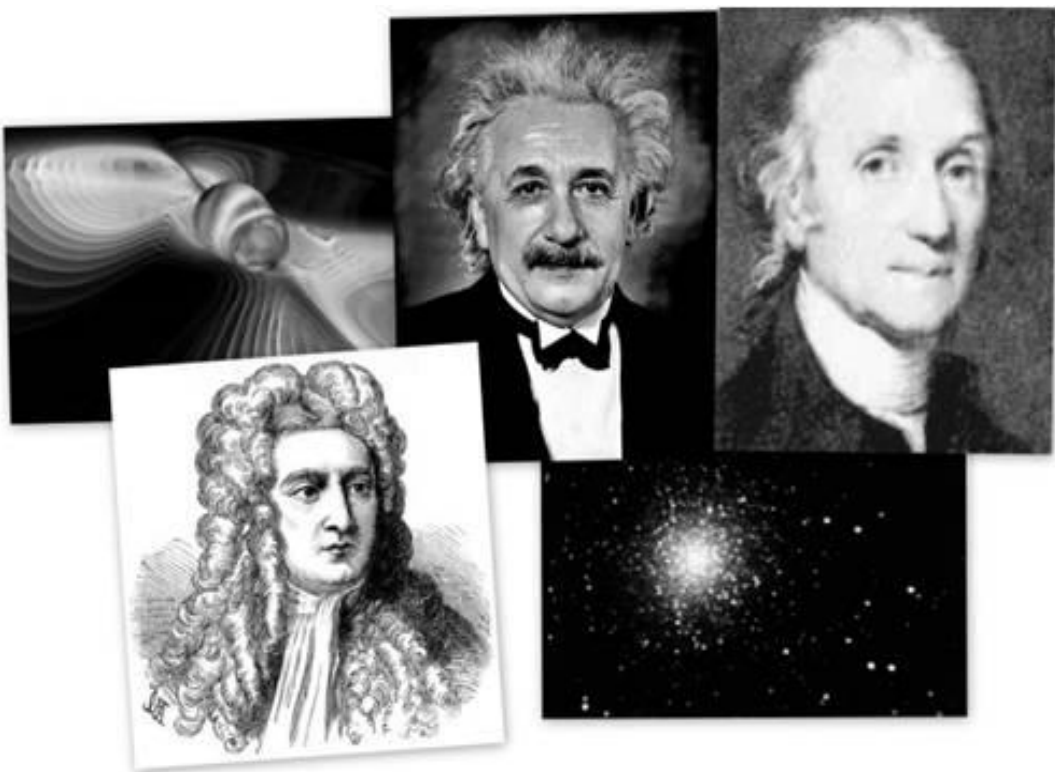


Since 2012 the existence of Higgs-particles seems to have been confirmed. The detection of particles having just the right energy level, proved the Higgs boson. The picture shows traces following collision of protons in the LHC at high energy level (By courtesy of CERN)

The four fundamental forces in the Universe:

- **nuclear forces of strong interaction**
- **nuclear forces of weak interaction**
- **electromagnetic forces**
- **gravity**

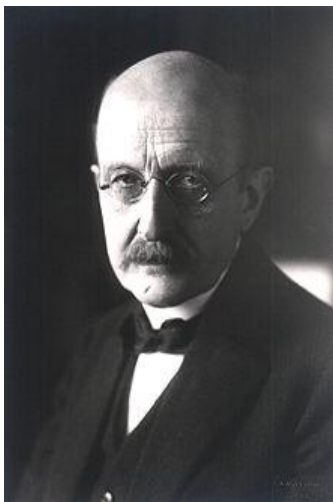
Any “Theory of Everything“, any final theory, ultimate theory or master theory must be able to embrace all four forces!



The Contribution of Quantum Physics

Beside Einstein's theory of relativity, there is another approach to exploring the secrets of space and time: Quantum Physics, focusing on very small objects having atomic sizes. This differs totally from astrophysics, dealing as it does with the world of the biggest. Nevertheless, the world of the micro cosmos does have a mysterious connection to the world of the macro cosmos. There is a relationship but physicists have yet to discover it.

The trailblazer for that what we call Quantum Physics and the forerunner of the String theory which followed later, was **Max Planck**. He was awarded the Nobel prize for Physics in 1919 for his discovery of the so called *energy quantum*, also known as *Planck's constant*. This constant is related to the quantization of light and matter. Planck originated *quantum physics* and was the first to consider the world to be digital.

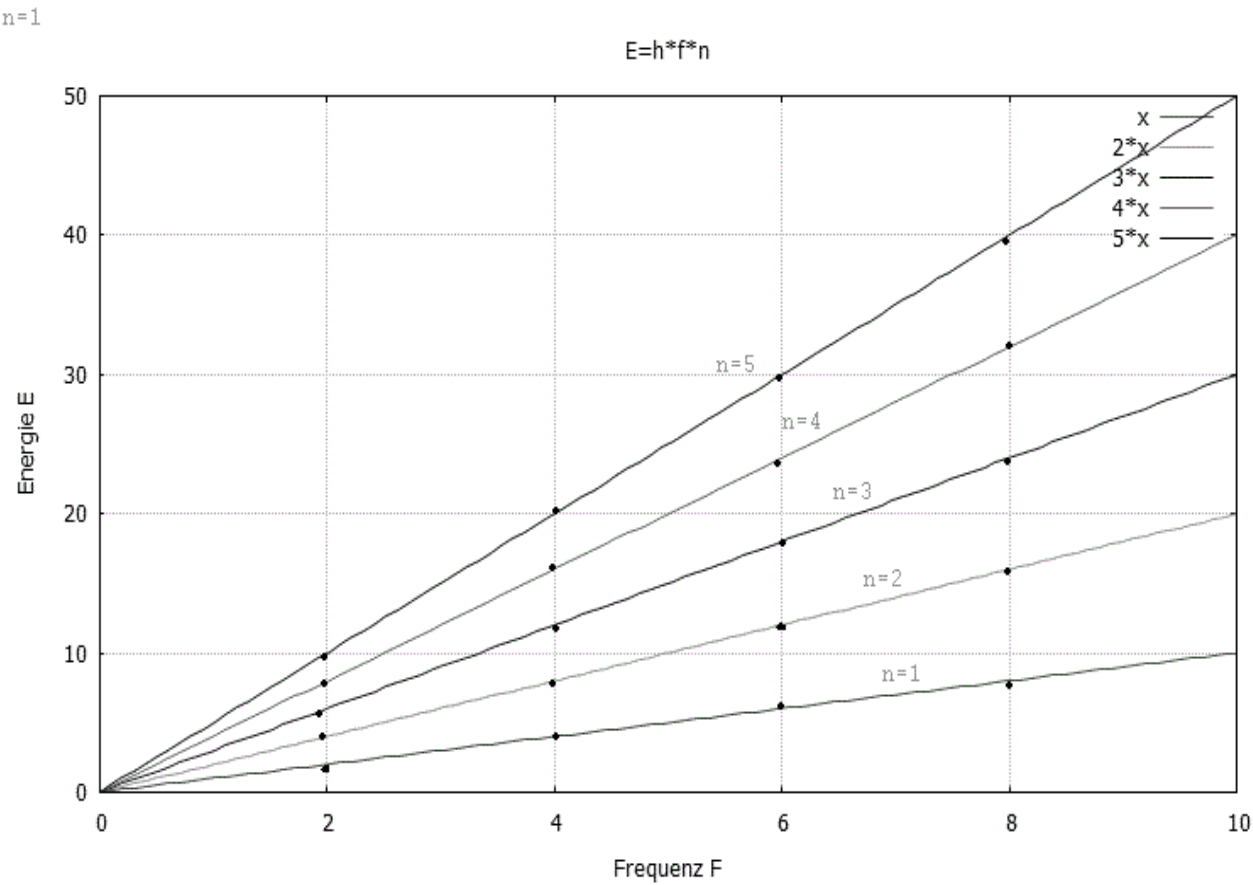


*Max Planck, Scientist, 1848 – 1947.
Planck coined the term “Quantum”
(Wiki)*

The most important scientific institution in the world is named in his honour: The Max Planck Society. This is a non-governmental and non-profit making association, comprising nearly 80 research institutes, working independently but cohesively.

Max Planck found his constant whilst investigating the problem of black-body emissions. He noticed that energy of that type of radiation is non-continuous, in other words, it exists in steps. Planck's formula is: $E = h \times f \times n$ where E equals Energy, f, frequency and h for the action quantum, n is any integer value (n=1,2,3...). h represents the *energy quantum* – this is a constant appearing in almost every formula related to the physics of black holes. The energy quantum is beside the gravitational constant G and the velocity of light c, one of the three fundamental nature constants of physics.. The value of the Planck constant is very small: $h = 0,000\,000\,000\,000\,000\,000\,000\,006\,626\text{ J}$.

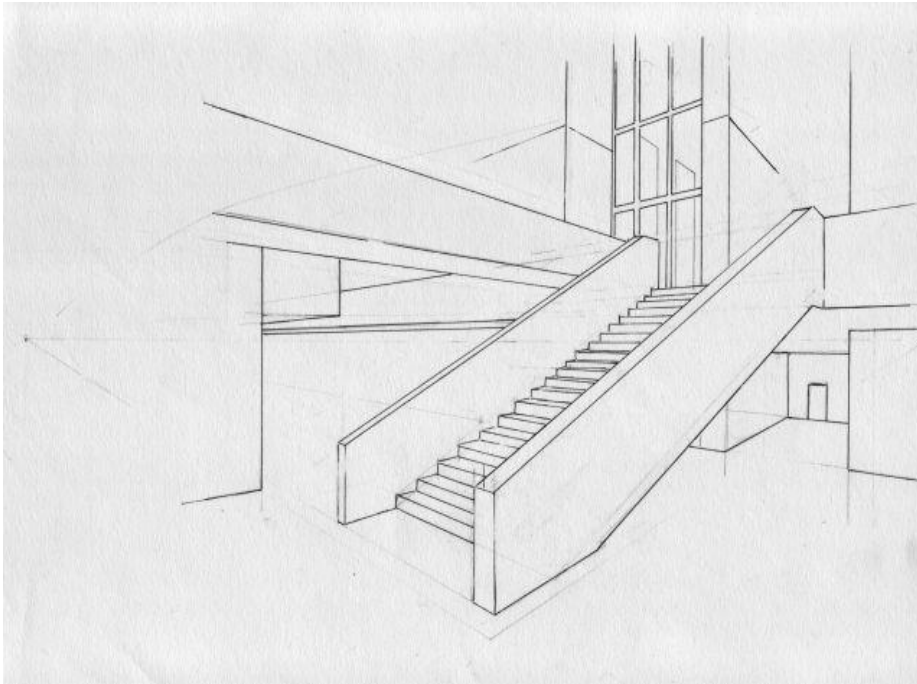
In the diagram below, random values were chosen solely to demonstrate the influence of n on the energy level applied at any frequency f. Clearly it can be seen that this energy level rises in steps. The relationship is also known as Planck relation



The integer n is closely related to the energy level which electrons may have in the Bohr atom. It depends upon in which shell the electrons are situated. Once an electron reaches the lowest level ($n=1$), it cannot get closer to the nucleus. This is identical to the state of lowest energy. Planck's calculations led to a result for the smallest possible length in the Universe, the so called *Planck length*. It is the smallest distance possible: about 10^{-35} m. It quickly transpired that there is also a Planck Mass, a Planck Time, a Planck Charge and a Planck Temperature. For black holes that would mean that the singularity must have at least the size of one Planck length, the said 10^{-35} m.

A Singularity cannot be any infinite point mass, as considered for some time but must have at least the finite length of Planck size. To take that to the extreme, another physicist and contributor to quantum physics, **Heisenberg** defined the *Uncertainty principle* which gives a fundamental limit to the precision with which particles can be predicted to be measured. Neither time nor location of any particles can be calculated precisely, only the probability of their existence. Intuition suggests that the Universe is not calculable: it is unpredictable. The Cosmos is not determinable in the sense that all is predetermined but chaotic and evolution occurs in small steps. This we all know from daily life. It should also be true for the black holes

**Everything happens in tiny steps, proposed
by Max Planck: the length (hence space and
volume), time, mass, charge, and
temperature**



Everything happens in tiny steps, proposed by Max Planck (Artist's impression: R.Brückner)

It is obviously impossible to describe the inside of a black hole by means of Einstein's theory of relativity. Equally, the mathematical formulae of Quantum Mechanics failed, even with the help of so called wave functions. Both theories have just one thing in common, i.e. The description of the world of space and time. The two theories are deficient in being unable to explain gravity. Currently, efforts are underway to define the quantum behaviour of a gravitational field, this with the help of new branches in Quantum Physics called *Quantum gravity* (QG) and *Quantum Chromodynamics* (QCD). All these theories are extensions and are derived from Planck's Quantum theory but largely failing to define gravity.

**Neither Einstein's Theory of Relativity
nor the equations of the quantum
physics are able to describe gravity.
Both theories are deficient**

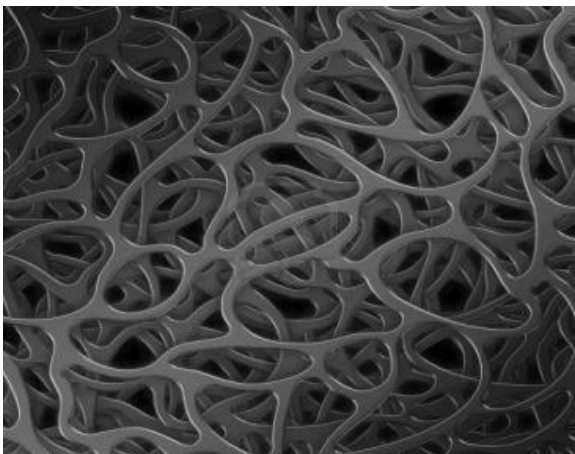
The Contribution of String Theory

New ideas were needed to solve the problem of quantum gravity. String theory came along, better known as String Theories because they are those which, for many people provide ongoing studies. String theory is more a theoretical framework trying to explain the four fundamental forces of the Universe. Its roots go back to Planck's action quantum in taking the Planck length – which has 10^{-35} Metres – as the smallest entity in the Universe. This is much smaller than any atom. New thought on the matter, involves the consideration by physicists that these strings might be able to oscillate. This would imbue Strings with undreamed-of possibilities.

*A String: The smallest possible entity in The Universe,
having solely one dimension at the size of a Planck length*

Having a single dimension and being the smallest possible entity in the Universe, they are able to oscillate but only in a longitudinal mode. They are regarded as sound, like strings on a guitar, able to vibrate at a very high tone. The wave-length is determined by Planck time, about 5×10^{-44} seconds. This Planck time is calculated by dividing the Planck length by the speed of the light. Like strings on a guitar they are anticipated to exhibit harmonics. Imagine the Universe vibrating to the sound of the strings and their overtones – a mighty concert. We can't hear them because the sound is not acoustic, but we are able to detect and measure it with the use of sensitive instruments.

Strings oscillate with a frequency of the Planck time, the shortest time step in the cosmos. They might vibrate in overtones. Due to the creative minds of the String theorists – most of them primarily mathematicians, these string harmonics generate space and matter and the charge of particles. Moreover, strings create dimensions of space, which will be caused by the oscillations of those strings and not only the common three with which we are familiar: length, width and height. Calculation has shown that up to 10 or 12 dimensions are required to explain the spatial curvature of The Universe. Hence, the supercube on page 34 could be caused by certain modes of oscillation of cosmic strings. The first three dimensions are we might expect. Further dimensions are created by a process called **Kaluza-Klein** compactification. But these further dimensions are said to be tiny – the reason why they will not easily be detectable. Cosmic Stings also could eventually form celestial objects, during a symmetry-breaking phase in the early Universe. This could have happened when the topology in the expanding Universe was distorted. The formation of cosmic strings is somewhat analogous to the imperfections that form cracks when water freezes into ice. Strings incorporate gravity and the theory of strings therefore is a candidate in the scramble for that *Theory of Everything*.



*Cosmic Strings
unfolding in higher
dimensions (Wiki)*



*Quantum foam as a mean of describing Space-Time by
using String Theory*

The Cosmos is filled with *Quantum foam*, as John Wheeler assumed, also referred to as space-time foam. It is a description of sub-atomic space-time turbulence at extremely small distances, on the order of the Planck-length. Moreover, quantum foam is thought to have created virtual particles of high energy able to shrink and interact with each other in such a way that superstrings appear which will accumulate, grow and become visible when proliferated into atomic sizes. There is not just one string theory but many. An abstract of all is called *M-Theory*, which calculates with eleven dimensions of spacetime interacting through membranes – or branes in short. Spoken simply, strings are able to elevate through the branes into higher dimensions, a process also called compactification. The ongoing progress leads to the *superstring theory*, including explanations for gravity. It might combine the previously mentioned theories of relativity and quantum physics in the future and hence string theory has the potential to become THE “theory of everything“, the most wanted theory at all. In 1996 the calculations of the entropy of black holes in using parts of the string theory were in accordance with Hawking’s former calculations. String theory mathematics is able to produce useful results.

The Power of Mathematics

Mathematics plays a major role for Black Holes because it is the only means of “looking“ into them. Visual observations are impossible. The event horizon is surrounded by invisible radiation, so mathematics must make the effort.

The use of mathematical means has some similarity to satellites which scientists may launch, in the hope of discovering meaningful answers about the structure of space. In many cases they succeed, sometimes with answers which are stunning. The premise behind that is to employ a precise method of questioning and a careful setting of the parameters, firmly based on facts. These settings must be derived from measurement, carefully undertaken. Moreover, a precise analysis of the results is crucial. If that is all done with a methodical approach, the mathematics can lead to quite acceptable conclusions, having relevance to the real world.



Mathematics is like a Magician, able to produce a rabbit from a top hat (Wiki)

Observed from the Earth, nothing can be seen or measured beyond the event horizon. Deductions can be made only by means of logic and mathematics. Hawking employed the so called “Euclidean Path Integrals“ to penetrate Black Holes by mathematics. The time t was substituted for space in using complex numbers, with help of the imaginary unit i (sometimes denoted by j). The imaginary unit i is a concept which extends the real number system to the complex number system. The core property is that $i^2 = -1$. The term “imaginary“ is necessary because no real number can have a negative square.

$$i^2 = -1$$

After a process called **Wick**-transformation, space-time is converted into space having four dimensions. The imaginary unit i makes it possible to transform time into space and vice versa. Calculations undertaken with complex numbers have been proved to produce precise results. Almost every day, we all utilize the imaginary unit by switching on the MP3-Player, digital radio or watching TV broadcasts. Preceding the transmission of the audio- and video content, after first digitizing, a process called “Fourier transformation“ is employed in accessing the use of the imaginary unit. Digital sound or frames are transformed between the so called “time domain“ and the “frequency domain“. In removing some redundant frequencies, the data can then be compressed heavily, to save bandwidth, transmission time and memory. Because this transformation process is quite reversible, the receiver can restore the original signal. That is an amazing performance, gaining benefit from complex numbers.

A further “juggling trick“ of mathematics allows deeper penetration into the black hole: with the help of the so called *AdS/CFT correspondence*, proposed by **Juan Maldacena** in late 1997. He combined a gravitational theory named “Anti de Sitter space“ (*AdS*) with the “Conformal Field Theory“ (*CFT*). In a nutshell, the n -dimensional *AdS* defines the world of the macro cosmos and link to the *CFT*, a quantum field theory, describing the world of the micro cosmos. The results are the “Maldacena duality“ or “Gravity Duality“, regarded as a powerful toolkit for the calculation of nuclear and condensed-matter physics. This is precisely what is required for revealing the secrets of the highly condensed cores of black holes.

As previously mentioned, many physicists are working on the superstring theory. Several ideas have been combined, leading to the so called *M-Theory*. This is an extension of the string theory in which 11 dimensions of space time have been identified. All these ideas converge in a model by the name of *Quantum Gravity*, describing the force of gravity according to the principles of Quantum Mechanics. Work continues and mathematics is the key.

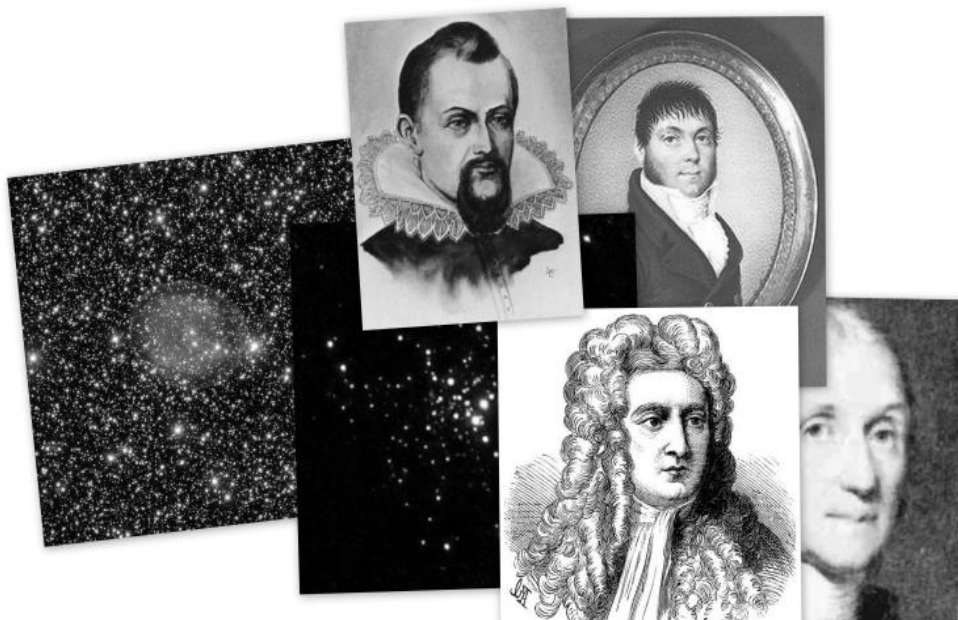
**Quantum Gravity is a theory combining
relativity and quantum theory, coupled
with the assistance of an extended string
theory**

A comprehensive theory of space and time must be able to explain the four fundamental forces to be found in the Universe, namely: the nuclear forces of strong and weak interaction, electromagnetic force and gravity.

It could be that, with the theory of Quantum Gravity, such a global and unambiguous theory will be found. Black holes should be included in such a self-inclusive “*Theory of Everything*“ Moreover, black holes could become the motivation for finding the key to a complete & unified theory of physics.

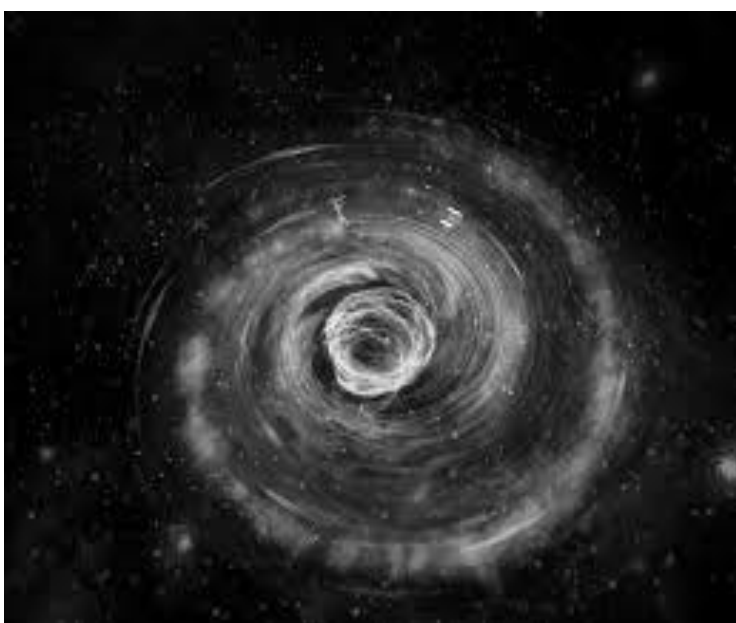
Hawking in his book “A Brief History of Time“:

“If we had a complete, unified theory of physics we could understand the thoughts of God“



Neither of the great theories – the Theory of Relativity and Quantum Mechanics – can explain behaviour of matter under extreme conditions. Nor can they explain the expansion of the Universe. Everything started with the Big Bang (see p. 39) when the primordial Universe, which was in an extreme, hot and dense state, began to expand rapidly.

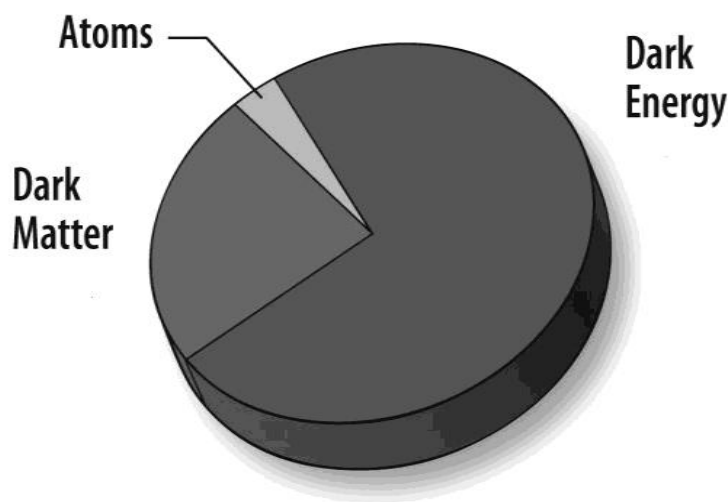
Before that, the entire early Universe was apparently concentrated in one single point, having all the same characteristics as a black hole: high density of matter (or energy – since Einstein, we do know that that's the same), collected into a single point. We speak of at least a 100 billion galaxies containing 100 billion stars (on average) aggregated into a point mass and could call them a *singularity*. This raises the question of whether or not the Big Bang was itself the result of a super-massive black hole 14 billion of years ago.



*Was the Big Bang
caused by a
Supermassive Black
Hole? (artist
impression, Wiki)*

Many questions remain:

- In Particle Physics, antimatter (composed of antiparticles) is missing almost entirely in nature. But why? Antimatter, in the form of individual antiparticles is commonly produced by particle accelerators like the Large Hadron Collider at CERN in Geneva. Their life-time is very brief and scientists claim that antimatter is the costliest material to make.
- The total mass of the Universe contains 5% ordinary atoms, or baryonic matter, 23% dark matter and 72% dark energy. Astrophysicists hypothesized dark matter and energy due to discrepancies between the orbital velocities of stars in the Milky Way and in star clusters, compared with their calculations. But what is the explanation?



Of what is the Universe really made?

The velocity of stars must be influenced by an invisible force in space. Gravity alone them cannot explain their orbital traces. Early theories of dark matter suggested black holes and Neutron stars as possible candidates for such irregularities. However, evidence indicated that such would constitute only a small portion of the discrepancies.

A key feature of Big Bang cosmology is the expansion of space. In the 1920s, astronomers like Edwin Hubble discovered that most galaxies exhibit a Red-Shift in spectra and that the red-shift was greater for more distant galaxies. From these observations they deduced that the Universe must still be expanding progressively. The Universe never *was* static. Dark Energy is the name given to whatever is causing the Universe's expansion to accelerate. Black holes might be a source of energy for dark energy. Supposed to be related to black holes, dark energy remains one of the greatest mysteries of science.

Maximillian Fabricius, working at the Max-Planck-Institut für extraterrestrische Physik (MPE) concluded in 2013:

- **Activity of Black Holes reached its climax 3 billion years after the Big Bang**
- **Each Black Hole can collect the mass of several Suns every year**
- **Every Galaxy has a Black Hole at its centre**

Current State of Research

Supermassive black holes with a mass of millions or even billions of suns are presumed to exist at the centre of almost every galaxy. How they came into existence and how their emerging influenced the development of the galaxies to which they belong, is currently the subject of research.

For example, ESO and MPI had confirmed that the strong radio source Sgr A* (pronounced Sagittarius A star) at the centre of the Milky Way is a super massive black hole.

Since 1992, its environment has been observed and monitored. This was done by a team focusing on the infrared wavelength. Since the advent of CCD cameras (replacing chemical film based on celluloid) the sensitivity of detectors has been extended into the red portion. By so doing, the orbits and the velocities of 28 stars have been measured.

Infrared cameras with the adaptive optics of the ESO in Chile were in use, also a spectrograph called Sinfoni, the Speckle-camera SHARP I and more instruments of the European Southern Observatory. Moreover, instruments of the Keck-Telescope in Hawaii, the New Technology Telescope and pictures taken by the Hubble-Telescope had been analysed. The result was that the massive matter at the centre of The Milky Way could only be explained by the existence of a rotating black hole. Almost 95% of the matter in that inner area of the Milky Way must have been aggregated there.

Further investigations, with the help of the “Very Large Telescope“ (VLT) of the ESO, carried out by astronomers of the “Max-Planck-Institute for Extraterrestrial Physics“ (MPE) in Garching near Munich, Germany, showed the ripping apart of a gas cloud. In 2013, it was the first time in history that this had been seen. This cloud is now making its closest approach and new VLT observations show that it is being grossly stretched by the extreme gravitational field of the black hole (see also the cover of this book).

Stefan Gillessen, leader of the observation team said:

"The gas at the head of the cloud is now stretched over more than 160 billion kilometres around the closest point of orbit to the black hole, and the closest approach is only slightly more than 25 billion kilometres from the black hole itself — barely escaping falling right in. The cloud is so stretched that the close approach is not a single event but rather a process that extends over a period of at least one year."

These photos are proof that black holes really do exist. They are also an explanation of the existence of a massive black hole at the centre in our galaxy containing approx. 4 million times the mass of The Sun. It is the closest known super massive black hole by far, hence it's the best place to study black holes in detail.

"The most exciting thing we now see in the new observations, is the head of the cloud coming back towards us at more than 10 million km/h along the orbit about 1% of the speed of light," adds **Reinhard Genzel**, leader of the research group which has studied this region for nearly twenty years

The European South Observatory is employing the flagship of its telescope fleet, to watch the black hole at the centre of our Milky Way. This is a telescope, in the Atacama desert, Chile, situated at the top of Mount Cerro Paranal. It is the previously mentioned, the so called “*Very Large Telescope*“, consisting of four identical telescopes having mirrors, each of which is 8 metres in diameter. The atmosphere on this mountain at a height of 2600 metres and is extremely clear and dry, making this an ideal place for an astronomer’s observation point.

The four telescopes can be combined as one large one, allowing astronomers to achieve detail up to 25 times finer than with an individual telescope. This technique is called VLTI. The I stands for “Interferometer“ and means that the light beams of the 4 huge telescopes are combined with a complex system of mirrors in underground tunnels. Here, the light paths must be maintained to within less than 1/1000 mm accuracy, over a hundred metres. With this kind of precision the VLTI can outperform the famous Hubble Space Telescope.



The Very Large Telescope VLT of ESA in Chile, consisting of four telescopes, each eight metres in diameter (By courtesy of ESA)

Supermassive Black Holes in other galaxies:

A top candidate for supermassive black holes was found at the centre of the galaxy M87, possessing mass equivalent to about 6.6 billions times that of The Sun. Record holder is a black hole containing approx. 21 billion times the mass of our Sun, located at the centre of the galaxy NGC 4889. This was detected in 2011. Also, a huge supermassive black hole of about 20 billion times that of The Sun, is the Quasar APM 08279+5255, discovered in 2011. In contrast, the black hole within the Milky Way is relatively small at a mass equivalence of 4 millions Suns.



The biggest Radio Telescope in world, at Arecibo, using a 300m diameter, parabolic dish. Big also means super-sensitive, i.e. the bigger the better (Wiki)

Because of the impossibility of optical observation of black holes, the use of Radio Telescopes for collecting the radio waves transmitted from the event horizon of black holes, is essential. Radio waves pass readily through dark clouds of hydrogen in space, allowing access to areas in the sky unavailable to traditional/classical telescopes. Moreover, radio telescopes can work together and be combined as one great “super“ telescope to reveal the secrets of the sky. Better still, by way of a bonus, they are able to work during day-light.

Gerhard Börner, Physicist at the MPI of Astrophysics in Garching, Munich said that the focus on black holes meanwhile has shifted. It is now set differently.

Important questions will have to be answered in the future:

- What are the fundamental characteristics of black holes?
- Will it ever be possible to make measurements close to or even beyond the event horizon?
- How will galaxies be influenced by the existence of supermassive black holes at their centre?

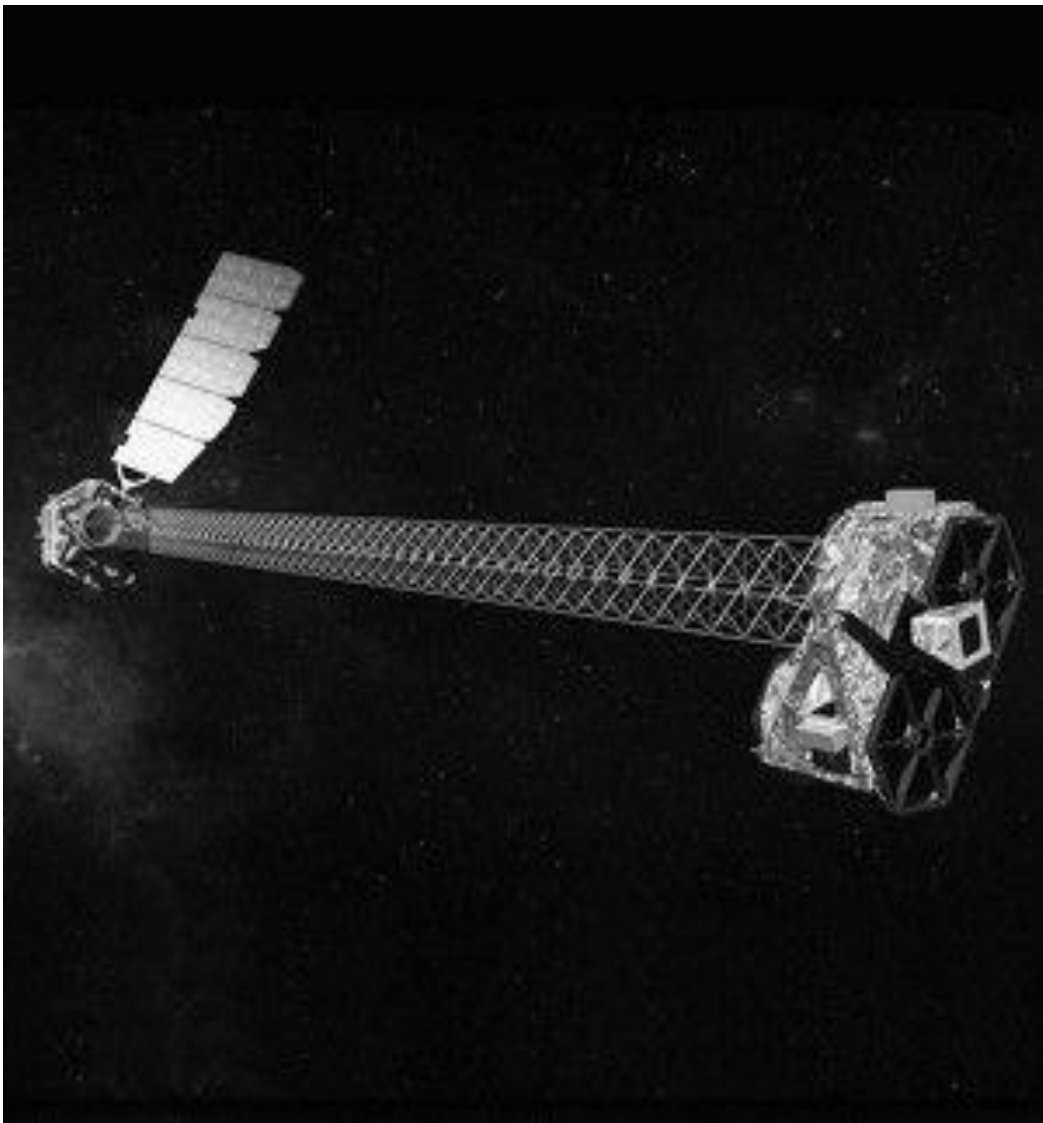
In his opinion, the observations with help of X-Rays and Gamma-rays will be most suitable to answer those questions.

That kind of electromagnetic radiation is to found in the jets at the poles of black holes and around the event horizon and very importantly, easy to detect owing to the high energy level which is emitted. He thinks such observations will be the key to understanding the interior of black holes



*X-ray satellite
Chandra of NASA,
in orbit since 1999
together with
another, the XMM-
Newton. (By
courtesy of NASA)*

Another X-ray satellite called **NuSTAR**, built by the American space agency NASA, was placed in orbit in June 2012. The satellite is designed to seek high-energetic electromagnetic waves and, when found, carry out further measurements. Because such radiation is anticipated to be emitted from black holes, this satellite will help to assess their energy levels and positions, helping to reveal further secrets. In 2015, a further satellite **eROSITA** will follow.



A X-ray satellite in a futuristic design: “Nuclear Spectroscopic Telescope Array“, NuSTAR, in orbit since 2012 (By courtesy of NASA)

Different Views

A *Black Star* is a theoretical alternative to a black hole. It is a gravitational object composed of matter but without need for any event horizon or singularity. However, this opinion does assign quite different parameters to them. It is argued that because of Quantum Physics, a singularity would need to exhibit at least the size of the Planck length which is 10^{-35} meter, the smallest entity in the Universe. Hence, it cannot be a point of infinite smallness, with zero elongation. Some scientists claim that such a singularity, simply cannot exist at the centre of a black hole.

Instead, Black Stars should be comprised of abnormal and degenerated matter, having a temperature inversely proportional their mass, as in the case of black holes. The rise in temperature which occurs when matter approaches the centre, gives black holes an internal temperature gradient. It is assumed that so called vacuum energy would stop a gravitational collapse from creating a singularity.

This Black Star prediction can be regarded merely as a slight variation of the common theory of black holes. The theory will not clash with that of black holes nor indeed, that of the Universe, as currently held in the scientific circles of the rest of the world. There was no need to coin any new wording. Also, the parameters of Black Stars will match almost but not quite that of black holes. They are, in theory, also celestial bodies whose gravity is so immense that not even light can escape their surface.

Epilogue

Could the Universe with its embedded black holes, really have appeared from nothing? A creation in a process, "ex nihilo" is essentially impossible. In physics, there usually is a reason for everything. Black holes play an important role in that act of creation and will retain all of their secrets because of their containing densely compacted matter. For that very reason they will remain at the forefront of research for a long time. As well as dealing with black holes, Astrophysicists answer questions other than those concerning matter under extreme conditions. They will also answer many of mankind's great puzzles, questions like "Who are we and where are we going?"

With the definition of black hole, two new terms entered the language, becoming widely used: The Event Horizon and The Singularity.

Perhaps the Singularity is a metaphor for God? If, in years to come, we finally succeed with the assistance of advanced telescopes, in gaining a deeper and wider view into Space, we may also find ourselves looking back in Time. Then, maybe we will be able to look back far enough to see the Universe and its early beginnings, its actual birth.

We will then perhaps see the very Big Bang itself. Thus, the world and how it was about 13.7 billion years ago, may be revealed. Looking in every direction, we would have a view into the singularity and able to report that perhaps we may even have seen God.

Some Books:

Stephen Hawking „A Brief History of Time“, Bantam Books

L.Susskind&J.Lindesay: „An Introduction to Black Holes, Information and the String Theory Revolution“, Amazon

J.P. McEvoy&Zarate „Quantum-Theory“ , Icon Books Ltd.

Brian Greene „The Elegant Universe“, W.Norton&Com Ltd.

Carl Sagan „Cosmos“ - Amazon

Caleb Scharf „Gravity´s Engines: The Other Side of Black Holes“, Amazon

Some Print Magazines:

UK´s astronomy magazine: “Astronomy Now“

UK´s astronomy magazine: “Sky at Night“

US magazine: “Sky & Telescope“

US magazine: “Astronomy“

German magazine: Spektrum der Wissenschaft, 5/2013:
“Giganten im All“

Some Internet Links:

www.eso.org/public/

www.eso.org/public/news/eso1332/

www.hubblesite.org - page of NASA

<http://home.web.cern.ch/topics/large-hadron-collider>

www.skyandtelescope.com - american magazine

www.lhc-facts.ch/img/news2013/blackhole.gif

www.universetoday.com

www.astronomynow.com

www.skyatnight.com

www.skyandtelescope.com

Compilation of mathematical plots in this book with the help of open software “Gnuplot“ under the GNU licence.

Image Permissions: Wikipedia, Wikimedia, by courtesy of the ESO press releases, NASA & JPL-Caltech and the CERN. Astro-Fotos taken by the author and amateurs of some public observatories, especially the VSW Munich.